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WATER RESOURCES
REPORT 7

Geology and Ground Water Resources of the Wilton Creek IHD Representative Drainage Basin

By
Gunter Funk

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

Toronto Ontario

1977

Additional copies of this report and other reports published in the "Water Resources Report" series may be obtained from the Hydrology & Monitoring Section, Water Resources Branch, Ontario Ministry of the Environment, 135 St. Clair Avenue West, Toronto Ontario, M4V 1P5.

PREFACE

This report represents a part of the Ontario Ministry of the Environment's contribution to the International Hydrological Decade (IHD) Representative Basin Program. This Program was initiated in 1965 to study five drainage basins in southern Ontario which were deemed to be representative of larger physiographic areas. The "Geology and Ground Water Resources of the Wilton Creek IHD Representative Drainage Basin" is the second in a series of several such reports.

G. H. Mills, Director
Water Resources Branch

Toronto, January 1977

WATER RESOURCES REPORT 7

Errata Sheet

Page	Particulars	Correction Needed
xi	Par. 4, Line 6	"then" should read "than"
9	Par. 3, Line 5	"Kinston" should read "Kingston"
41	Table 8	average transmissibility for overburden and bedrock wells combined, "2,400" should read "2,300".
42	Par. 4, Line 1	"mull hypothesis" should read "null hypothesis"
63	Par. 1, Line 6	should read "...Harrowsmith-Hartington area".
63	Par. 4, Line 6	"HCO_3/SO_3" should read "HCO_3/SO_4"
63	Par. 6, Line 11	"then" should read "than"
64	Line 3	"then" should read "than"
64	Par. 2, Line 14	"supples" should read "supplies"
64	Tabular, Line 4	delete "Chloride"
65	Par. 2, Line 4	"supples" should read "supplies"
79	Location 5, Thickness 10-20 Feet:	"forsets" should read "foresets"
83	Section B, Thickness 2 Feet:	should read ..."foreset beds dip to the southwest"
84	Location 14,	"Qunite" should read "Quinte"
92	Table 13, Bottom Line	"softner" should read "softener"

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ENGLISH - METRIC (SI) FACTORS

to convert	to	multiply by
inches (in)	centimeters (cm)	2.540
feet (ft)	meters (m)	0.305
miles (miles)	kilometers (km)	1.609
square miles (sq. miles)	square kilometers(km^2)	2.590
cubic feet/sec.(cfs)	litres/sec.(l/sec)	28.316
Imperial gallons (Ig)	litres (l)	4.546
Imperial gallons/day(Igpd)	litres/sec.(l/sec)	5.262×10^{-5}
Imperial gallons/day - ft^2 ($Igpd/ft^2$)	meters/sec.(m/sec)	5.663×10^{-7}
Imperial gallons/day - ft (Igpd/ft)	square meters/sec.(m^2/sec)	1.726×10^{-7}

ABSTRACT

This report describes the geology and ground-water resources of the Wilton Creek drainage basin. The Wilton Creek drainage basin was chosen for study because it is representative of a large area in southeastern Ontario characterized by a limestone plain with sparse to nonexistent overburden cover.

The bedrock is comprised of Cambrian and Ordovician sedimentary rocks lying non-conformably above Precambrian rocks of Grenville age. The sedimentary rocks consist of the conglomerates, sandstones and shales of the Basal Group, and the carbonates of the Simcoe Group. The overburden is primarily of Pleistocene origin deposited during the last Wisconsin ice advance.

The carbonate bedrock constitutes the major aquifer. The overburden is too thin and discontinuous to have anything but a localized affect on the hydrogeology.

The quantity of water available for use is difficult to predict because it is dependent on the number of interstitial openings encountered during well drilling and their degree of interconnection. Productivities of wells finished in different hydrogeologic settings vary significantly. In the basin, well productivities tend to be higher for shallow wells then deep wells and higher for wells finished in valleys as opposed to upland areas.

For the interval, 1967-68 and 1973-74, the mean precipitation over the basin is estimated to be 37.04 inches. The mean total streamflow is 16.40 inches of which 3.97 inches or 24.2% is estimated to be baseflow. Evapotranspiration as calculated by the Munson-Index method is 22.68 inches and by the indirect or water-balance method, 20.64 inches.

The chemical quality of the surface water is good. The ground-water quality varies with location and depth of sample. Most samples are of the calcium-bicarbonate type. With the exceptions of some of the deep well water samples, the waters are satisfactory for domestic uses.

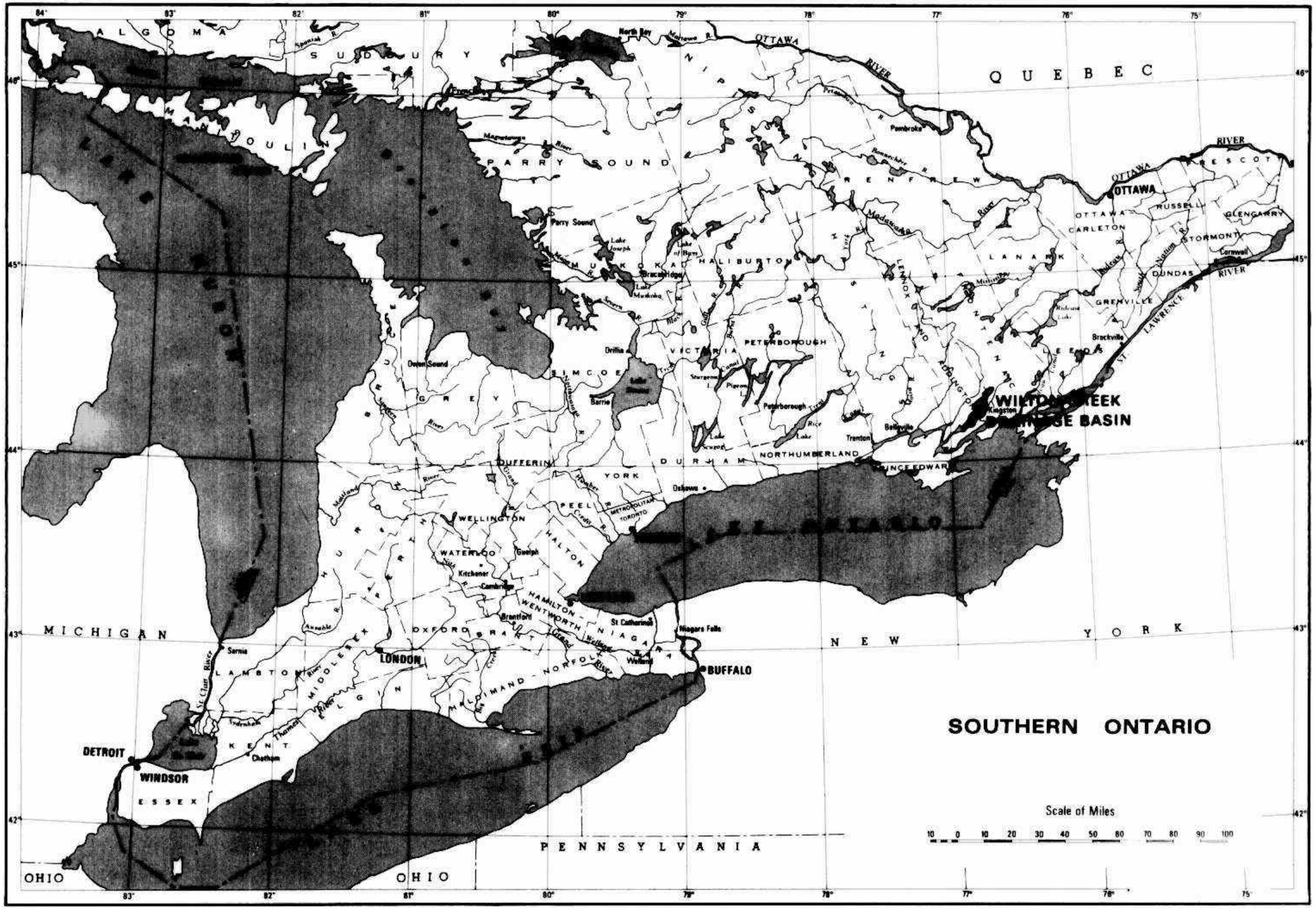


Figure 1. Location of the Wilton Creek drainage basin in southern Ontario.

INTRODUCTION

SCOPE OF PRESENT INVESTIGATION

This study of the ground-water potential and the relationships amongst the geology, water quality and water availability was undertaken in the Wilton Creek drainage basin by the Ontario Ministry of the Environment, as part of the International Hydrological Decade (IHD) Representative Basin Program. The geologic and ground-water data used in this study were compiled from existing reports (both published and unpublished), water-well records, and detailed field mapping undertaken during the summer of 1973. The field work included extensive road geology, selected traverses, air-photo interpretation and overburden sampling. Stratigraphic cross sections were compiled using data from existing sand and gravel pits. Hand augering was employed in areas where exposures were lacking. In addition, water samples from selected wells in the basin were collected in order to determine the chemical composition of the ground water.

The bedrock geology was compiled using the guidelines suggested by B.A. Liberty (pers. comm.). The surficial geology was supplemented with information provided by E. Mirynech (unpublished field notes).

PREVIOUS GEOLOGICAL INVESTIGATIONS

The Precambrian stratigraphy of the Canadian Shield to the north and underlying the basin is comprised of a variety of lithologic types including meta-sedimentary, volcanic and intrusive rocks. The adjacent shield area and Frontenac Axis have been mapped in detail by Wynne-Edwards (1962, 1967a) and Hewitt (1963). The Precambrian surface is an irregularly peneplained terrain with a relief in some areas of 350 feet (Liberty, 1971). The irregular relief is transposed under the Paleozoic covering, as represented by numerous Precambrian inliers in eastern Ontario.

Overlying the Precambrian rocks non-conformably are the Paleozoic rocks of the late Cambrian to Middle Ordovician periods. The Paleozoic stratigraphy, as described by Liberty (1967, 1969, 1971), Peterson (1969), and Dolar-Mantuani (1975), consists of a sedimentary sequence including basal conglomerates, sandstones, shales and carbonaceous rocks.

The overburden of Pleistocene and Recent age is comprised of glacial, glaciofluvial and glaciolacustrine sediments deposited during the last ice advance (Wisconsin), and alluvium and muck deposits. The area was mapped by Coleman (1936), Chapman and Putnam (1966) and on a more detailed scale by Mirynech (unpublished field notes).

ACKNOWLEDGEMENTS

The study was carried out under the direction of R.C. Hore, Supervisor, Hydrology and Monitoring Section, with assistance provided by staff. The author is particularly indebted to Messrs. R.C. Ostry, S.N. Singer and J. Coward for their information and assistance, Messrs. R.C. Hore and F.C. Fleischer for their critical review of this study, and Ms. S.D. Hambly for the many hours spent typing this manuscript. The author especially wants to thank Dr. B.A. Liberty and Dr. E. Mirynech, both of Brock University, for their discussions with the author and the abundance of data made available. In addition, the co-operation extended by local residents in the area is appreciated.

GEOGRAPHY

LOCATION

The Wilton Creek drainage basin lies in southeastern Ontario between longitudes 76° 37' and 76° 57', and latitudes 44° 10' and 44° 28'. It is situated about 12 miles west of the City of Kingston and is readily accessible by highways #2, #38, #133 and #401 and a network of county and township roads. Both the Canadian Pacific and Canadian National railways traverse the basin.

The drainage basin is approximately 56.6 sq. miles in area and is essentially linear in shape, running northeast to southwest. The maximum length of the basin is 23.8 miles and the maximum width is 3.5 miles. The position of the basin with respect to southeastern Ontario is shown in Figure 1.

PHYSIOGRAPHY

The drainage basin lies within a physiographic subdivision referred to by Chapman and Putman (1966) as the "Napanee Plain". This area is characterized by a flat plain of limestone dipping gently to the southwest, resulting in a series of shallow erosional scarps. Relief in the area is in part the result of erosion by stream drainage and erosion by past glaciations. In the northern portion of the basin, relief is approximately 100 feet, while in the south it is about 50 feet.

Coleman (1936) suggested that jointing controls the orientation of topographic features such as escarpments and river valleys in southeastern Ontario. This controlling factor is reflected in the general trend of Wilton Creek. The fractures in the limestone bedrock have a prevailing northeast to southwesterly trend.

The overburden is generally sparse to non-existent in the basin. Relief in the southern portion of the basin and in low-lying areas such as the valley proper, has been modified by localized accumulations of overburden.

The major urban centres, in order of size, are: Harrowsmith, Wilton, Morven and Violet. A land use study undertaken in the basin in 1969 by the Ministry of the Environment, indicates that the primary industry is agriculture, with dairy farming comprising the greatest acreage.

CLIMATE

The drainage basin lies within Brown, McKay and Chapman's (1968) South Slopes climatic regime. The climate is influenced by the moderating effects of Lake Ontario. As a result, the growing season is typically 190-200 days long and extends from the middle of May to late November. The mean maximum and mean minimum monthly temperatures and mean monthly temperatures for the Hartington area for the interval 1968-1973 are presented in Table 1. During this interval, the mean annual temperature was 43.3°F. The lowest mean monthly temperature, 15.0°F occurred in January and the maximum mean monthly temperature, 68.4°F, occurred in July. The mean monthly precipitation for Hartington and Violet from 1968-1973 is shown in Table 2. The mean annual precipitation for that interval was 36.33 and 36.44 inches, respectively.

TABLE 1. MEAN MAXIMUM AND MEAN MINIMUM MONTHLY TEMPERATURES (^{O}F) FOR THE HARTINGTON CLIMATOLOGICAL STATION FOR THE INTERVAL 1968-1973

Monthly Temperature	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly
Mean Maximum	23.6	25.3	35.8	50.2	63.1	72.6	78.6	77.6	70.0	57.1	40.9	27.2	51.8
Mean Minimum	6.3	8.8	20.5	32.3	43.7	55.1	58.3	57.5	51.6	41.2	29.7	13.0	34.8
Mean	15.0	17.1	28.1	41.2	53.4	63.8	68.4	67.5	60.8	49.1	35.3	20.1	43.3

TABLE 2. MEAN MONTHLY PRECIPITATION (INCHES) FOR HARTINGTON AND VIOLET FOR THE INTERVAL 1968-1973

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly
Hartington	1.88	2.86	2.65	2.01	3.60	3.34	3.16	2.75	3.25	2.89	3.71	4.23	36.33
Violet	2.20	2.71	2.43	2.56	3.30	2.91	2.44	2.63	3.51	3.05	3.65	5.05	36.44

TABLE 3. COMPARATIVE STRATIGRAPHY FOR THE WILTON CREEK AREA (MODIFIED AFTER LIBERTY, 1969)

G. M. Kay 1960 Biostratigraphic Divisions			Liberty 1969 Biostratigraphic Divisions			Liberty 1964 and 1969 Lithostratigraphic Divisions			Peterson 1969 Lithostratigraphic Divisions	Liberty 1971 Lithostratigraphic Divisions			Time
Trentonian	Pictonian	Cobourgian	Barneveld	Trentonian	Cobourgian	Simcoe Group	Verulam Formation	Upper		Verulam Formation			Middle Ordovician
		Shermanian			Shermanian			Lower					
	Nealmontian	Kirkfieldian											
		Rocklandian	Wilderness		Nealmontian		Bobcaygeon Fm.	U M L		Bobcaygeon Fm.	Upper Lower		
Blackriveran				Bolarian	Chaumontian		Gull River Formation	Upper	Cycle III	Gull River Formation	Member D		
					Lowvillian			Middle	Cycle II		Member C		
											Member B		
									Cycle I		Member A	Upper submember	
					Pamelian			Lower	Lower Limestone			Middle submember	
									Basal Clastics Unit			Lower submember	
						Basal Gp.	Shadow Lake Formation		Shadow Lake Formation	Shadow Lake Formation			
Precambrian			Precambrian			Precambrian			Potsdam Formation	Potsdam Formation			Cambro-Ordovician
									Precambrian	Precambrian			Precambrian

BEDROCK GEOLOGY

With the exception of the Potsdam Formation, the entire stratigraphic section as summarized by Liberty (1971) is exposed in the Wilton Creek drainage basin (Appendix A and Map 1). The outcrop exposures range from Precambrian to Middle Ordovician in age. The Potsdam Formation is inferred to be present from water-well logs.

The stratigraphic sequences as interpreted most recently by Kay (1960), Liberty (1969, 1971) and Peterson (1969) are presented in Table 3.

PRECAMBRIAN

The Precambrian bedrock, Grenville in age, has been mapped primarily as gneisses, schists, and granites, crystalline limestone and dolomite, amphibolite, paragneiss, volcanics and pegmatite. The Precambrian can be found exposed only at one location, northeast of Harrowsmith. At this locality, an inlier of granite gneiss with an estimated relief of 75 feet (as determined from adjacent water-well logs) is exposed. The Precambrian and Paleozoic contact at this location is shown in Photo 1a. The contact at a location east of Wilton Creek near Inverary Lake is shown in Photo 1b.

Photo 1a. Contact between Shadow Lake Formation and underlying Precambrian northeast of Harrowsmith.

BASAL GROUP

Lying non-conformably above the Precambrian is a series of beds known as the "Basal Group". This Basal Group represents a shallow water depositional facies immediately above a period of erosion. The Basal Group is divided into two units, the Potsdam and Shadow Lake formations. This sedimentary sequence has an overlapping relationship with the Precambrian Shield in the area of the Frontenac Axis, as is suggested by exposures of Paleozoics on the flanks of Precambrian highs (Figure 2).

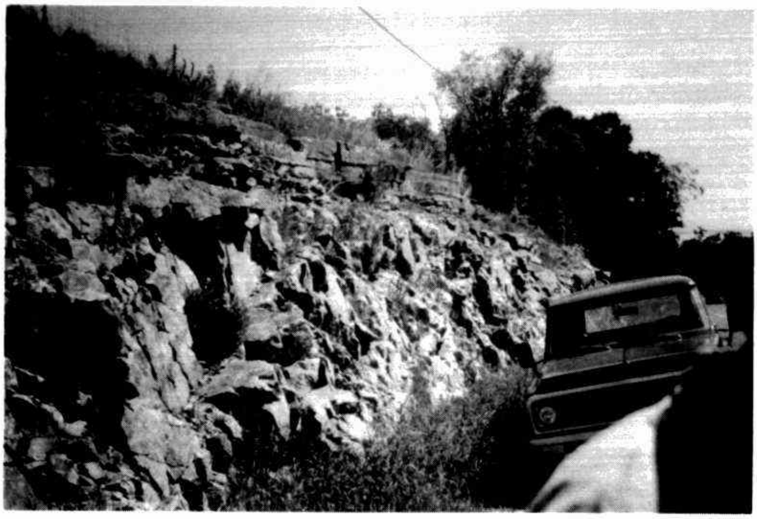


Photo 1b. Angular unconformity between Precambrian and overlying Shadow Lake Formation. Photo taken near Inverary Lake north of Kingston.

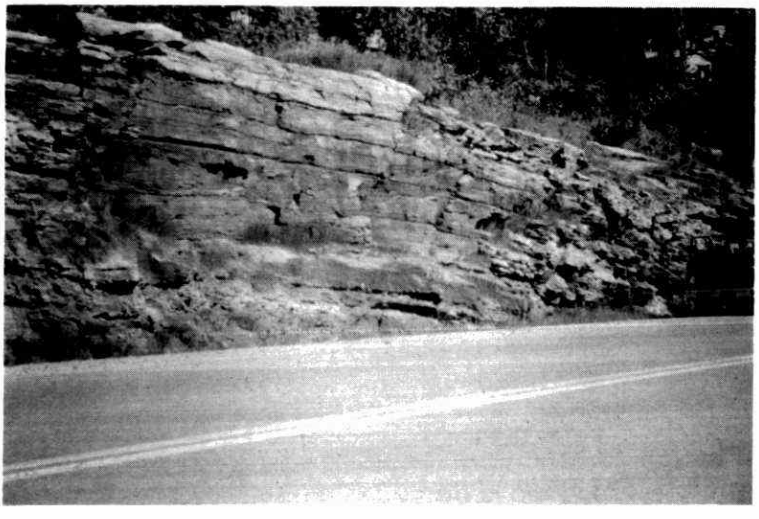


Photo 2. A road cut exposing the Potsdam Formation east of the drainage basin near Brewers Mills.

Normally present at the contact between the Paleozoic and Precambrian rocks is a basal conglomerate composed of rock fragments reflecting the underlying bedrock material. This conglomerate is time transgressant, occurring as high in the stratigraphic sequence as the Gull River Formation, where the older formations are not present.

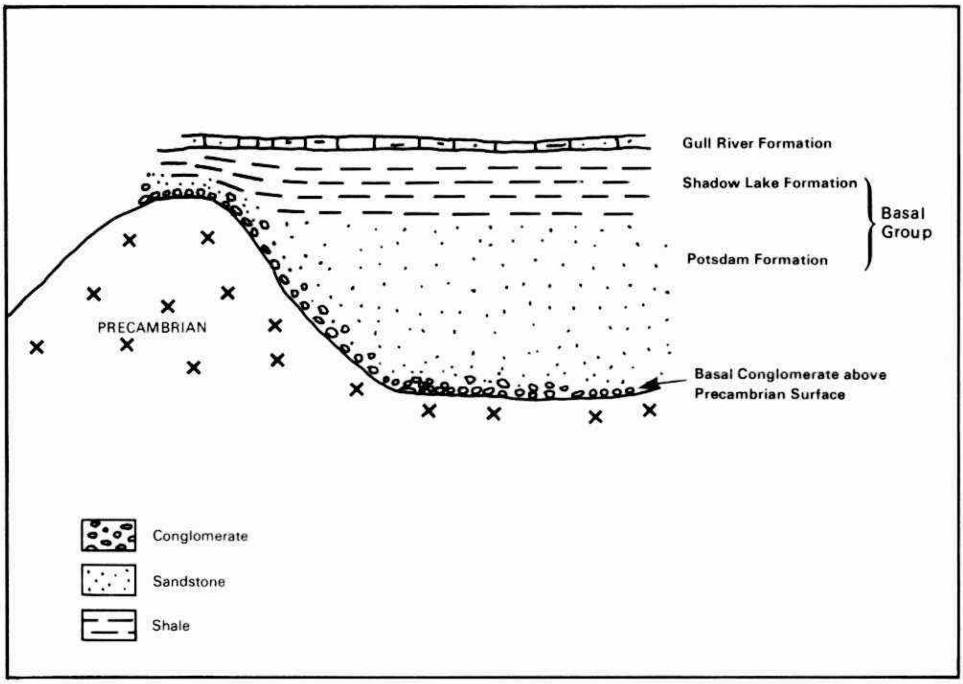


Figure 2. Generalized diagram illustrating the overlapping of the sedimentary sequence on Precambrian highs.

Potsdam Formation

The Potsdam Formation, whose type-section is in northern New York State, is generally considered to be Cambrian in age, although evidence for this is lacking in Ontario. The occurrence in Ontario of the fauna Lingula acuminata and Ophileta compacta indicates an Ordovician age for at least the upper part of the Potsdam (Wilson, 1946 and Liberty, 1971).

Liberty (1971) recorded a maximum thickness of 149 feet for the Potsdam Formation in the Knowlton Lake-Holleford area. This thickness is a result of deposition in a Precambrian low, which has been attributed to a "meteorite impact crater". The near circular shape of the "crater" is evident from air photos of the area. A detailed study of the "crater" by St. John (1968) supports the meteorite impact origin.

The Potsdam Formation outcrops just to the east of the basin, on the west shore of Knowlton Lake. It consists of an even-textured, medium-grained, white to red quartz sandstone, cemented by hematite and calcite. From water-well logs, the average thickness is about 30 feet in the basin area. The Potsdam Formation, where it outcrops northeast of Kingston, is shown in photos 2 and 3.

Photo 3. Vertical cylindrical structures in the Potsdam Formation at the Park of Pillars.

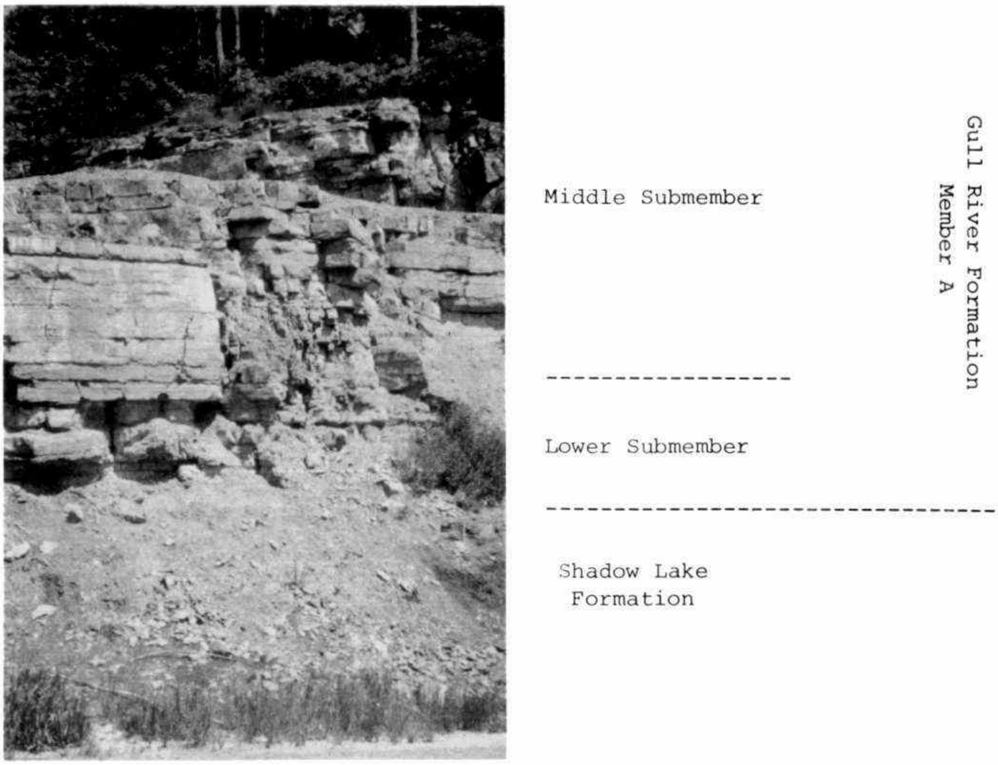


Photo 4. Contact between the Shadow Lake Formation and the overlying Gull River Formation near Inverary Lake. The Shadow Lake Formation is represented by a black and green shale. Both the lower and middle submembers of Member A of the Gull River are exposed.

Shadow Lake Formation

The Shadow Lake Formation, first named by Okulitch (1939), was redefined by Liberty (1955, 1969) to include only the red, green and black shales and arkoses that lie unconformably above the Precambrian and the Potsdam Formation. Okulitch had originally included the lower 4-5 feet of the Gull River Formation, an argillaceous limestone.

The Shadow Lake Formation, which has not been differentiated from the Potsdam Formation in the water-well logs, can be found draping the Precambrian inlier north of Harrowsmith (Photo 1a). The sequence exposed (about 2 feet) represents a vertical facies change from a basal paraconglomerate to an arkose, then to a shale. The conglomerate fragments, in addition to an abundance of quartz and jasper pebbles, reflect the lithology of the underlying Precambrian surface. The shale, a green and red-mottled claystone with a high carbonate content, contains pockets of arenaceous material. The uppermost contact is between the black and green shale beds of the Shadow Lake Formation containing the ostrocod Ctenobolbina clavigera, and the overlying shaly limestone of the Gull River Formation, (Photo 4). This formation appears to be about 20 feet thick in the vicinity of the basin.

SIMCOE GROUP

The Simcoe Group (Liberty, 1955, 1963, 1969, 1971) is divisible into four formations, which in ascending order are: the Gull River, Bobcaygeon, Verulam and Lindsay. Only the first three can be found in the basin area, the Lindsay outcropping further west. The Simcoe Group is approximately 700 feet thick in the Kinston area, while in the Wilton Creek area the thickness is only about 400 feet.

Gull River Formation

The Gull River Formation was defined by Liberty (1969) to include the strata lying between the Shadow Lake Formation and the fine to medium-grained limestones of the Bobcaygeon Formation. The Gull River was sub-divided by Liberty (1971) into four members (A to D). In the Wilton Creek area however, the repetition of lithology and the difficulty in correlation requires the grouping of members B, C and D into one mappable unit. Peterson (1969) sub-divided the Gull River Formation into a "lower limestone" and three separate cycles on the basis of lithology and faunal progression (Table 3). Peterson's identification guidelines are not incorporated into this study.

Member A.... Member A has been sub-divided into three mappable submembers (Liberty, 1971) in the Kingston area. The lower and middle submembers are grouped together by the author on the bedrock map (Map 1). The lower submember is gray to brown to green, strongly-weathered, soft, crystalline to lithographic limestone with thin dolostone beds. Liberty (pers. com.) suggested that the texture of these beds, as well as the soft beds higher in the sequence, is related to dedolomization. The alkali-reactivity of these carbonate rocks and this dedolomization phenomenon is described in Dolar-Mantuani (1975). This submember is about 2-5 feet thick in the Kingston area (Photo 4).

The middle submember is a brown to dark brown weathering lithographic limestone, with a distinctive purplish hue on fresh surfaces. In some areas, this submember takes on a mottled, digitate appearance. Soft dedolmitized beds (0.5-1.5 feet in thickness), which are strongly weathered, occur at intervals throughout the section. Mineral molds and calcite crystals are abundant, often resulting in a pitted and characteristic wormy, weathered surface. In the basin, the maximum thickness of the middle submember is approximately 70 feet. The upper contact has been drawn at the base of an unfossiliferous black shale phase of the upper submember (Liberty - pers. comm.), (Photo 5).

Photo 5. Contact between the middle and upper submember of Member A of the Gull River Formation, represented by black shale. Photo was taken near Inverary Lake.

The upper submember is an alternating gray, sublithographic to lithographic limestone with brown, soft to hard, fine-grained to finely crystalline dolomitic limestone and dolomite beds. Shaly partings and horizons are frequent in the sequence, as are calcite vugs, mineral molds, limey conglomerates and calcarenites. Dolomitic limestone beds, fcund just above the upper contact of this submember, can be used as marker beds, where they are traceable over the upper portion of the basin. Bedding is relatively uniform and varies from 0.1 to 1.5 feet in thickness, while the overall thickness is approximately 90-100 feet. The upper submember can be seen at the Highways 401-15 and Highway 401 - Montreal Road roadcuts (photos 6a. and b.).

Member B.... Member B has been sub-divided into two submembers, the lower submember having a thickness of approximately 20 feet and the upper having a thickness of approximately 40 feet. The contacts between members A and B and between the lower and upper submembers of Member B are exposed in a roadcut at Highway 401 and Montreal Road intersection east of Kingston, (photos 7a. and b.).

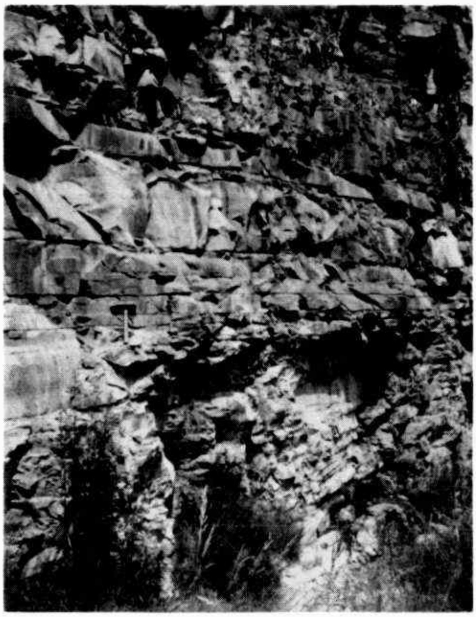


Photo 6a.

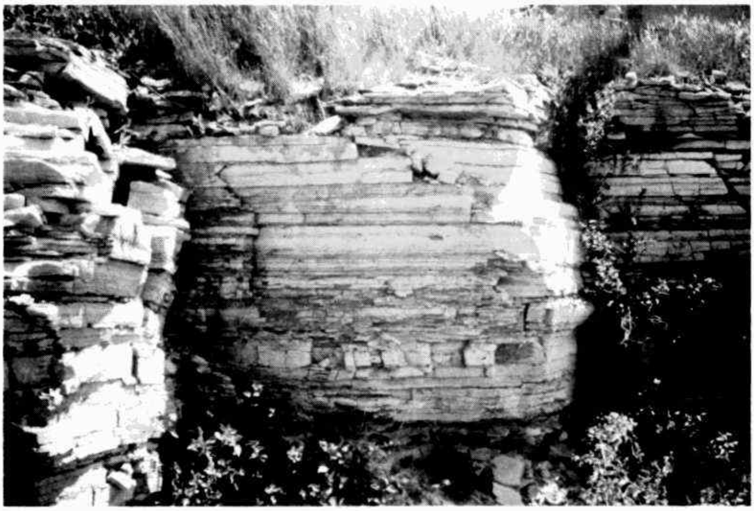
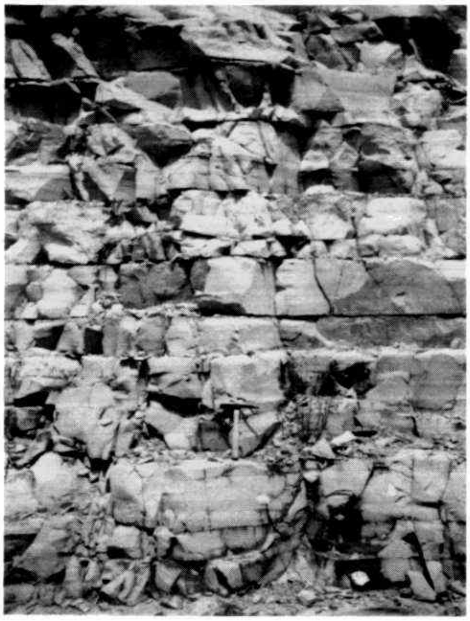


Photo 6b.

Photo 6a. and b. The upper submember of Member A of the Gull River Formation, taken at Highway 401 roadcuts, near Kingston.



Lower B

Upper A

- Note calcite vugs

Phota 7a. Contact between Members A and B of the Gull River Formation at the Highway 401 and Montreal Road intersection.

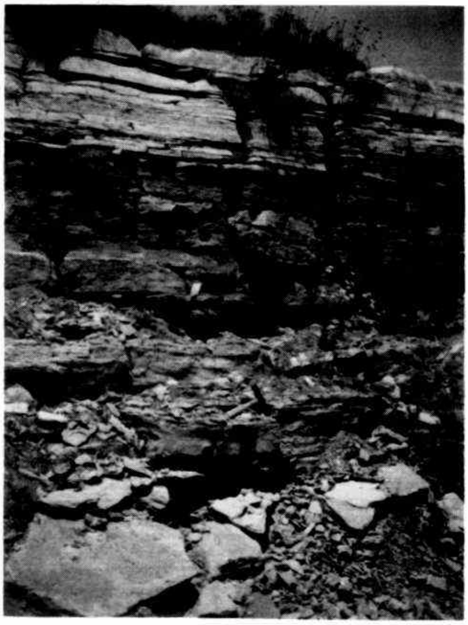


Photo 7b. Upper submember of Member B of the Gull River Formation west of Highway 401 and Montreal Road intersection.

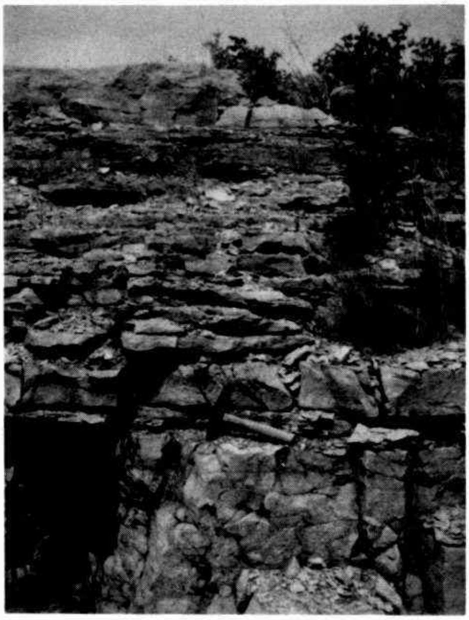


Photo 8. Member C at the highways 401 and 38 intersection, note the alternating beds of shale with lithographic limestone.

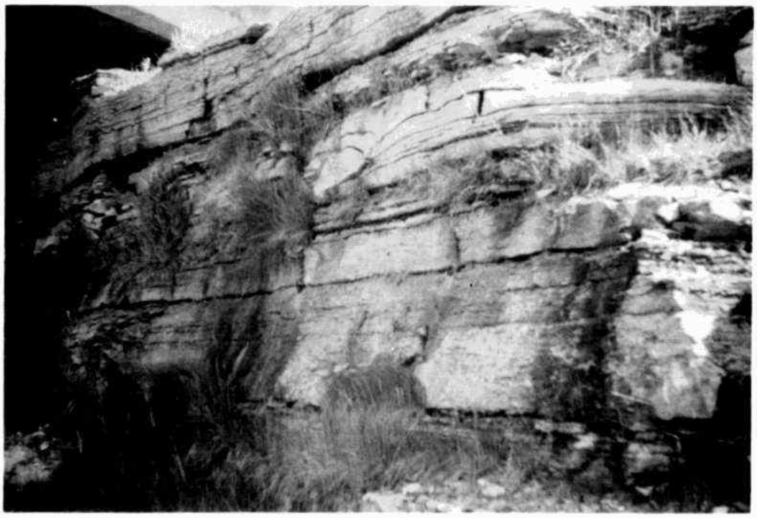


Photo 9a. Stromatolite zones at the highways 401 and 38 intersection.

Photo 9b. Stromatolite zones at the highways 401 and 38 intersection.

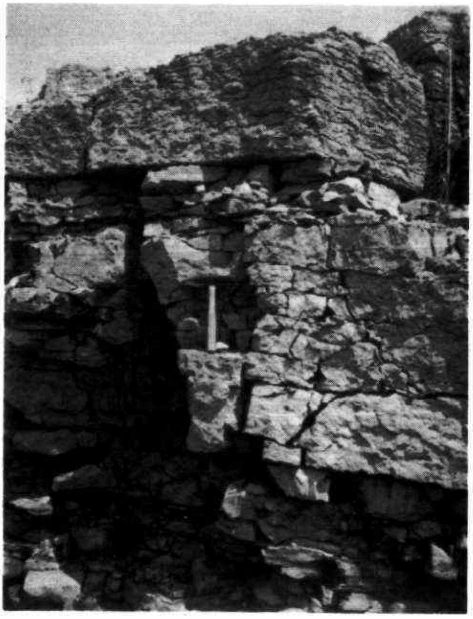


Photo 10. Member D exposed south of the highways 401 and 38 intersection.

The lower submember consists of thin to medium beds of gray lithographic limestone. This member is used as a building stone in Southern Ontario because of its uniform texture and hardness. In places it is almost pelletoidal, while at other localities it is thinly laminated.

The upper submember ranges from a fine, semi-crystalline, lithographic limestone to a clastic, fossiliferous, argillaceous limestone. Its appearance varies locally; however, it can be distinguished from the underlying beds by its fossil content and from the overlying Member C by its lack of stromatolite zones.

Member C.... This member, described in detail by Greggs and Sargent (1971), is approximately 20 feet thick. It is essentially an alternation of thin to thick beds of dark gray, lithographic limestone and shale with massive beds of grey, semi-crystalline and lithographic limestone, which are locally fossiliferous (Photo 8). This member is charcterized by four clastic carbonate zones containing stromatolites, the uppermost zone of which is continuous throughout the Kingston area (Peterson, 1969). The abundant fossil species were found by Greggs and Sargent to be time transgressive, thus difficult to use for correlation purposes. Structural features include mudcracks, cross-beds and ripple marks. Stromatolites beds and ripple marks are shown in photos 9a and 9b.

Member D.... This uppermost member has been termed a "mixed" unit by Liberty (pers. comm.) on the basis of the wide range of grain sizes present in any one hand specimen (from sublithographic to finely granular limestone). This member is composed essentially of massive beds (2-5 feet), although thinner shaly beds are common. It is highly fossiliferous, locally containing yellow-orange flakes of oxidized material and weathering to a gray-buff colour, with a gritty texture. Member D, as well as Member C, is exposed in a roadcut at the highways 401-38 intersection (photo 10). Although only about 15 feet of Member D is present in the basin, Liberty (1971) has recorded thicknesses of up to 55 feet in a roadcut east of Camden. The uppermost member has only been found in the Kingston and northern New York State areas and has not been traceable west of Napanee.

Bobcaygeon Formation

The Bobcaygeon Formation, as originally named and defined by Liberty (1963), is a lithogenetic unit lying between the lithographic limestone of the Gull River Formation and the interbedded limestones and shales of the Verulam Formation. The unit has been sub-divided into two members, 15-feet and 5-10 feet thick, respectively. The lower member, exposed near the Camden Road - Highway 401 intersection, consists of a fine calcarenitic limestone with occasional beds of sublithographic limestone (Photo 11). The member is highly fossiliferous, the dominant fauna include Receptaculites occidentalis, Tetradium cellulosum, Dalmanella rogata, and Maclurites logani.

The upper member, although equally fossiliferous, is less resistant to weathering and is often thick-bedded. It is essentially a gray, sublithographic limestone and claystone with a blue-gray, irregularly pitted, weathering surface.

The Bobcaygeon Formation is biostratigraphically correlated with the Chaumont-Rockland-Leray-Hull strata, while lithologically the Formation can be traced into the uppermost Bony Falls Formation in Michigan and the Leray-Rockland beds of the Ottawa Formation in the Ottawa Valley (Liberty, 1969).

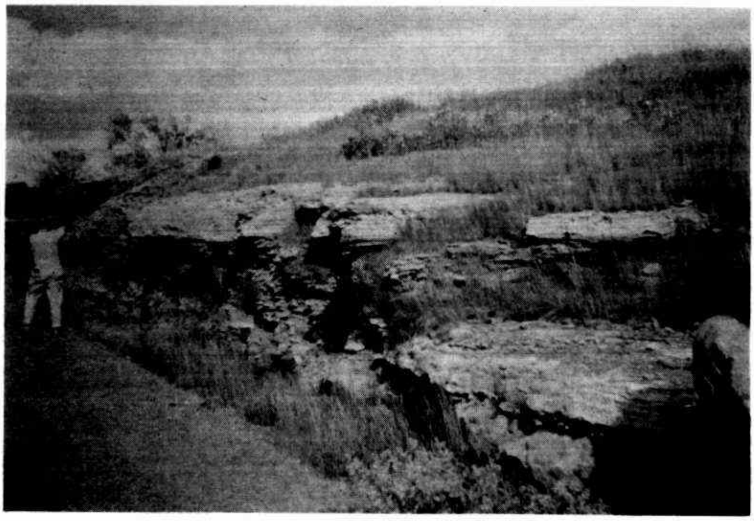


Photo 11. Contact between the Gull River and Bobcaygeon formations as represented by beds of fossiliferous limstone overlying beds of sublithographic limestone. Photo taken near intersection of highways 401 and 133.

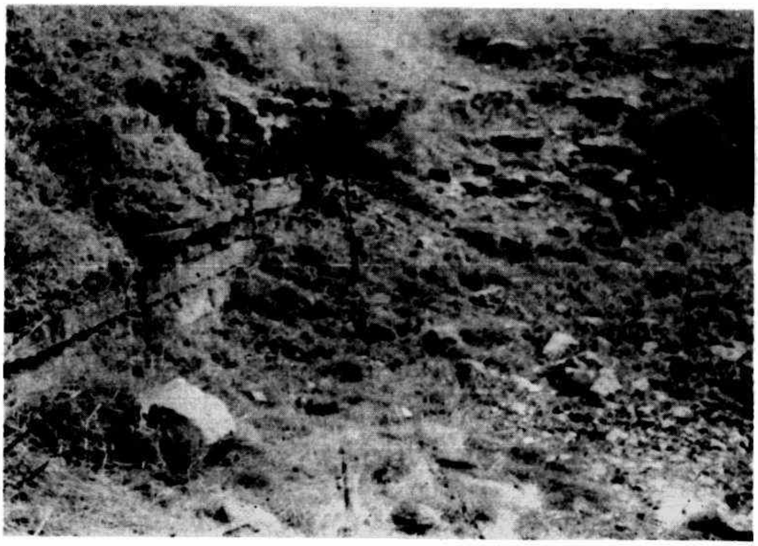


Photo 12. Verulam Formation exposed in an abandoned quarry in the area south of Morven.

Verulam Formation

The Verulam Formation, after Liberty (1955), is the youngest bedrock formation found in the Wilton Creek area. It is characterized by alternating bands of fine to medium-grained crystalline limestone and weathered, calcareous claystone, with shale partings (Photo 12). Only the lower-most unit is exposed in the area. This unit is highly fossiliferous with an abundance of "Prasoporid" bryozoans. The abundant fauna include: "Dalmanella", "Prasopora" and echinoderms. Many of the fossils have been silicified, as can be seen at three abandoned quarries south of Chambers. The lack of exposure limits the control on bedrock contacts; therefore, the bedrock map (Map 1) in the southern part of the basin is relatively unchanged from Liberty (1971). Liberty (1971) estimated the thickness of the Formation to be about 350 feet in the Kingston area. The Verulam Formation is correlated with the Sherman Fall and lower-most Cobourg formations of New York State and the Ottawa Valley (Liberty, 1971).

BEDROCK STRUCTURE

The linear nature of the drainage basins and various structural features in southeastern Ontario appear to parallel the general trend of the Grenville Structural Province. The Precambrian rocks of the Grenville Province, have a northeasterly strike. Wynn-Edwards (1967b) suggests that the metasedimentary rocks in the Grenville have undergone a complex stage of folding and refolding resulting in a system of northeast-trending folds. These folds were subsequently reduced by erosion to a peneplained condition, the anticlinal fold axes remnant as shallow linear ridges. These ridges can be traced under the Paleozoic cover as is evident from scattered inliers. Major drainage features in the Precambrian can be traced upward into the Paleozoic rocks. Liberty (1971) suggests that the Precambrian surface topography is of major importance in the relief and distribution of the younger bedrock formations in the area.

The Precambrian surface dips to the south, while the overlying Paleozoic formations dip south to southwest. The measured regional dip for the Simcoe Group in the Wilton Creek area is between 20 and 50 feet per mile, becoming steeper to the north.

Several northeast-trending faults occur in the Napanee-Kingston area, as the result of post-depositional (Paleozoic) basement movements. The largest displacement (100 feet) has been recorded in the Napanee area (Liberty, 1971). Figure 3, a cross-section of the basin near Violet, presents the gamma-ray logs obtained from six MOE observation wells. From the logs, it is evident that the units are easily traceable across the valley, with two, 20-foot vertical displacements occurring, one on the north side and one on the south side of the creek. The northeasterly trend of Wilton Creek, in addition to these displacements, may suggest fault control of the creek.

The gamma-ray logs measure the inherent natural radioactivities of the rock units, with shales and shaly limestones generally showing a higher radioactivity than clean limestones and sandstones; therefore, in a gamma-ray log, the peaks in the intensity will correspond to shales, while the lows will indicate limestones, sandstones, etc. Digesting limestone samples correlating with high and low gamma values, in both dilute HCl acid and ethylenediaminetetraacetic acid (EDTA), indicate that the high radioactive samples have twice the shale (undigested remains) as the low samples. No attempt has been made to relate the gamma-ray logs to Liberty's stratigraphic sequence. At the present no continuous gamma-ray logs exist from the Precambrian upward into the Ordovician units in this area.

Feature and joint orientation measurements for the Wilton Creek area are presented on the bedrock map (Map 1). These orientations which were obtained in quarries and other outcrop exposures, are grouped together by area. There appears to be some correlation between the major fracture trends and the trend of Wilton Creek. Both the fracture trend and the trend of Wilton Creek are roughly oriented between 30° and 50°. This suggests that the faulting was along fracture planes.

OVERBURDEN GEOLOGY

The Wilton Creek drainage basin is blanketed by deposits of glacial, glaciofluvial and glaciolacustrine origin, representing deposition during the Wisconsinan stage of the Pleistocene Epoch. The glacial features, both erosional and depositional, indicate that ice movement was south-southwest.

During deglaciation, meltwaters created a series of proglacial lakes in the Lake Ontario basin. These lake stages resulted in the formation of a number of 'abandoned beaches', marking stands in water levels. The best known stage, that of Lake Iroquois, is not represented in the Kingston -Napanee area. It is assumed that Lake Iroquois was ponded against the ice margin in this area. The lack of any substantial thicknesses of deposits, and the repetitive nature of some of the sediments in the Wilton Creek drainage basin, suggests deposition along a fluctuating ice front followed by a rapid lowering of the proglacial lake stages to the Lake Ontario stage. Local deposits of alluvium and muck of Recent age can also be found within the basin. The areal distribution of the Pleistocene and Recent deposits is indicated on Map 2.

The overburden thicknesses, as shown on the isopach thickness map (Map 3), averages about 3-5 feet on the bedrock highs and about 20-25 feet in the bedrock valley. Local accumulations of sands and gravels in the bedrock valley have a maximum recorded thickness on the order of 90 feet.

A generalized stratigraphic sequence compiled from various roadcuts and sand pits within the drainage basin is listed below (Table 4).

TABLE 4. GENERALIZED STRATIGRAPHIC SEQUENCE IN THE WILTON CREEK AREA

Stage	Event or Formation	Lithology
Recent:	Alluvium, marsh deposits	gravel, sand, silt, clay, muck, peat
Late Wisconsinan:	Lake Belleville beach deposits	gravel and sand
	Undifferentiated glacial, glaciofluvial and glaciolacustrine deposits	gravel, sand, silt, clay, till
	Glaciofluvial deposits	gravel and sand
Upper Ordovician:	Simcoe Group	limestone and shale

DIRECTION OF ICE MOVEMENT

A number of glacial features can be used to determine the approximate direction of ice movement. In the Wilton Creek drainage basin, these features include striations, grooves and drumlins (Photo 13). The observed orientations are presented on the accompanying overburden geology map (Map 2) and are summarized below on Table 5.

TABLE 5. GLACIAL FEATURE ORIENTATIONS

Location	Feature	Trends
Harrowsmith and north	Striations	234° - 242°
Harrowsmith - Wilton	Striations	226°
	Drumlins	225° - 233°
Wilton - Violet	Striations	234° - 240°
	Grooves	227°
	Drumlins	233° - 237°
Violet to lower basin boundary	Striations	234° - 256°
	Drumlins	232° - 242°

A visual comparison of the orientation of the creek valley resulting from faulting with the glacial orientations would appear to indicate that the preglacial topography added considerable control to glacial flow. Local striation directions strongly reflect the local valley trends (Map 2).

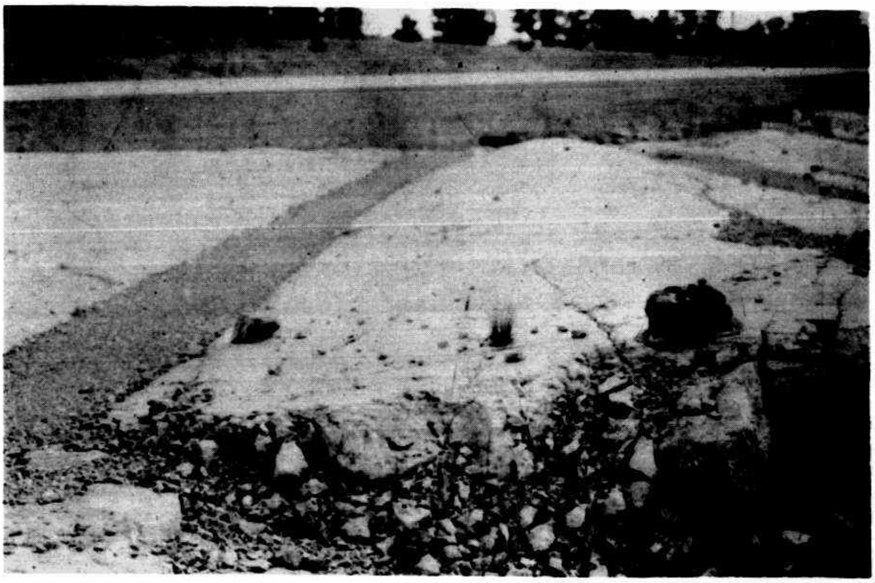


Photo 13. Glacial whaleback forms on Highway 401 near the Highway 133 intersection.

GLACIAL DEPOSITS

The term "glacial deposit" is used here to refer to unconsolidated sediments deposited by direct glacial action and includes both till and stratified material incorporated within the till. The glacial deposits in the Wilton Creek drainage basin are thin and discontinuous, averaging about 3-5 feet thick in the north.

The till, based on mechanical analyses presented later in the report, is typically sandy to silty with a higher clay content in the deposits in the southern reaches of the basin. It appears that the clay content in this area is from the incorporation of glaciolacustrine sediments into the till by the overriding of these sediments by the ice front. Three thin but stratigraphically distinctive till layers are present in the Wilton-Violet area. These layers are interbedded with glaciofluvial and glaciolacustrine sediments as is characteristic of deposition along an oscillating ice front. Similarly, clay balls can be found incorporated in the till near the contact between the till and glaciolacustrine clay. The interbedded Pleistocene deposits near Wilton are shown in Photo 14, while descriptive logs for roadcuts and pit exposures are presented in Appendix 1.

Drumlins are present in the south and central portions of the basin. These drumlins, which belong to the Quinte drumlin field, are characterized by their low relief and elongated ridge-like nature (Mirynech, 1967). Photo 15 shows an elongated drumlin south of Morven. The average dimensions for length, width and height of the drumlins are 1000 x 300 x 25 feet, respectively, while the average trend is 235°.

Two basic types of drumlins are present; those composed entirely of till and those with a stratified sand and gravel core. The first type, being more abundant, can be found throughout the Napanee - Kingston area. The latter type has been described in detail by Deane (1950) and examples can be found locally within the drainage basin. A typical example of this type of drumlin is present southeast of Thorpe (Photo 16). At this locality, a gravel pit is cut into the side of the drumlin exposing sand and gravel and about 3 feet of overlying till. Water well #1218, which has been drilled into this drumlin, encounters 10 feet of loam and 26 feet of sand and gravel.

GLACIOFLUVIAL DEPOSITS

The term "glaciofluvial" is applied to deposits of unconsolidated sediments (coarse silt to gravel) laid down by meltwater streams. These deposits are characterized by the well sorted and stratified nature of the materials. Both cross and graded bedding are common structural features related to these deposits.

In the study area, extensive glaciofluvial deposits can be found on bedrock terraces in the creek valley. Photo 17 shows sand and gravel deposits on bedrock terraces near the community of Wilton.

A subglacial origin is postulated for these glaciofluvial materials, the sand and gravel being deposited in ice caverns adjacent to and on bedrock terraces by subglacial meltwater streams. Thin layers of till and clay can occasionally be found interbedded with the sand and gravel. The largest sand and gravel deposit underlies Morven. Water-well logs indicate the presence of up to 90 feet of sand and gravel in a bedrock depression. Other large deposits of this type underlie the lacustrine clay near the mouth of Wilton Creek.

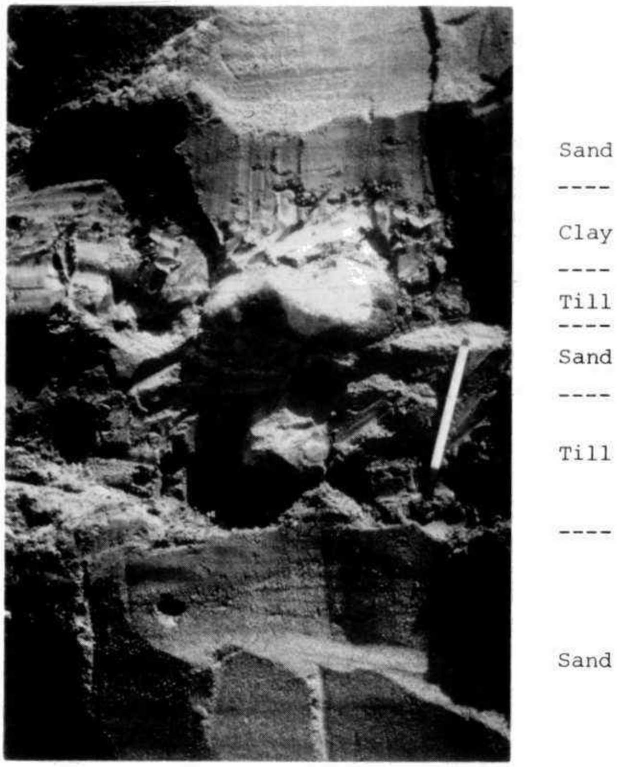


Photo 14. Interbedded till, clay and sand near Violet at the sanitary landfill site.

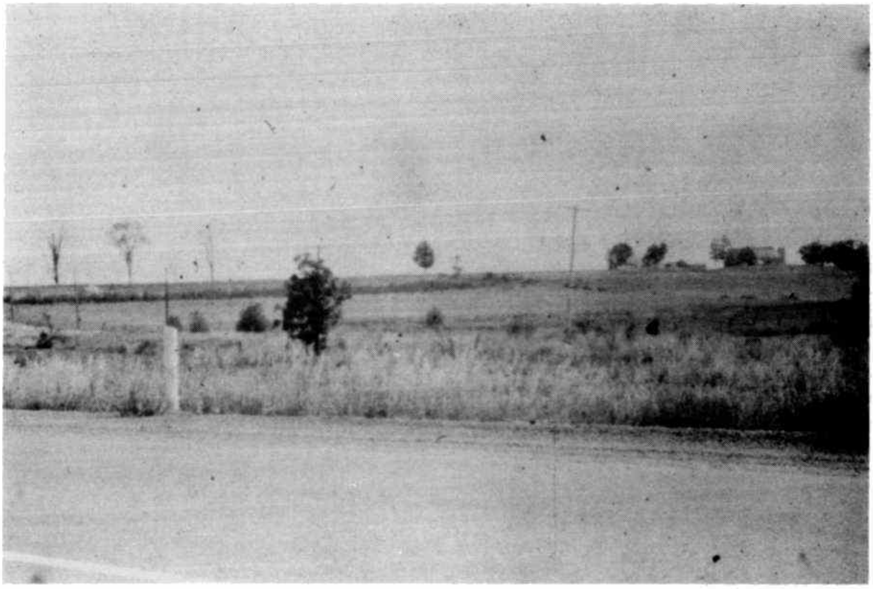


Photo 15. Elongated drumlin south of Morven.

Photo 16. Drumlin with a sand and gravel core, in the Thorpe area.

Photo 17. Sand and gravel deposits on bedrock terraces near Wilton.

The glaciofluvial deposits near Harrowsmith and Wilton are presently being used as a source of sand and gravel for local road and building construction. Scott (1971), in his examination of engineering properties of these deposits, obtained an approximate volume measurement of 100,000 cubic yards for the one near Harrowsmith. He estimated the area of deposit near Wilton to be on the order of 1,000,000 square feet (Photo 18). Map 4 indicates the approximate and assumed extent of known sand and gravel deposits in the drainage basin.

In the northern portion of the basin, two miles east of Hartington, a sand, gravel and till plug acts as the drainage divide between Wilton Creek and Knowlton Lake. This plug measuring about 600 feet by 200 feet completely fills the local bedrock valley (Figure 4). A seismic refraction and electrical resistivity survey was carried out by the Ministry of Environment in order to determine the thickness of the overburden. The following stratigraphic sequence was interpreted from the results of this survey:

	Depth Range (maximum)	
Unit	Resistivity	Seismic
sand or sandy till (dry)	0-5 feet	0-43 feet
sand and gravel (wet)	5-25 feet	
till or fractured bedrock	25 feet	43 feet

The approximate thicknesses for the overburden at various stations on the plug are indicated in Figure 4. The maximum assumed thickness is 43 feet. This plug was probably deposited during the final recession of the ice sheet.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine deposits are defined as those deposits which were laid down in lakes adjacent to glacial ice masses, the materials being delivered to the lakes by meltwater streams. Particle sizes range from clay (deep water) to sand and gravel (nearshore and beach environments).

The glaciolacustrine clay and silt found interbedded with the glacial and glaciofluvial sediments in the Wilton Creek valley and adjacent low-lying areas are attributed to deposition in Lake Iroquois along a floating ice front. The clay in general become increasingly siltier towards the north as would be expected in a sedimentary progression (particle size increasing with decreasing distance from the glacial source). The glaciolacustrine deposits vary in thickness from 2 to 5 feet, the thicker beds occurring in topographic depressions.

The clay and silt in the south-central portion of the valley can be subdivided into an upper and lower unit; the lower unit being more compact and darker in colour then the upper unit. Compression tests conducted on two similar clays in in the Kingston area suggest that the lower clay was glacially overridden (Sangrey, 1970). This would support the concept of a fluctuating ice sheet in this portion of southeastern Ontario.

Varved clay is only exposed in one area, the sanitary landfill site south of Violet. At this locality, glacial till is overlain by about 3 feet of varved clay. The varved clay is overlain by another till layer, suggesting that its occurrence is the result of local ponding. Clay balls can be found incorporated in the upper till, near the till-clay contact. This may indicate turbulent water conditions prior to the advance of the ice front and subsequent till deposition.

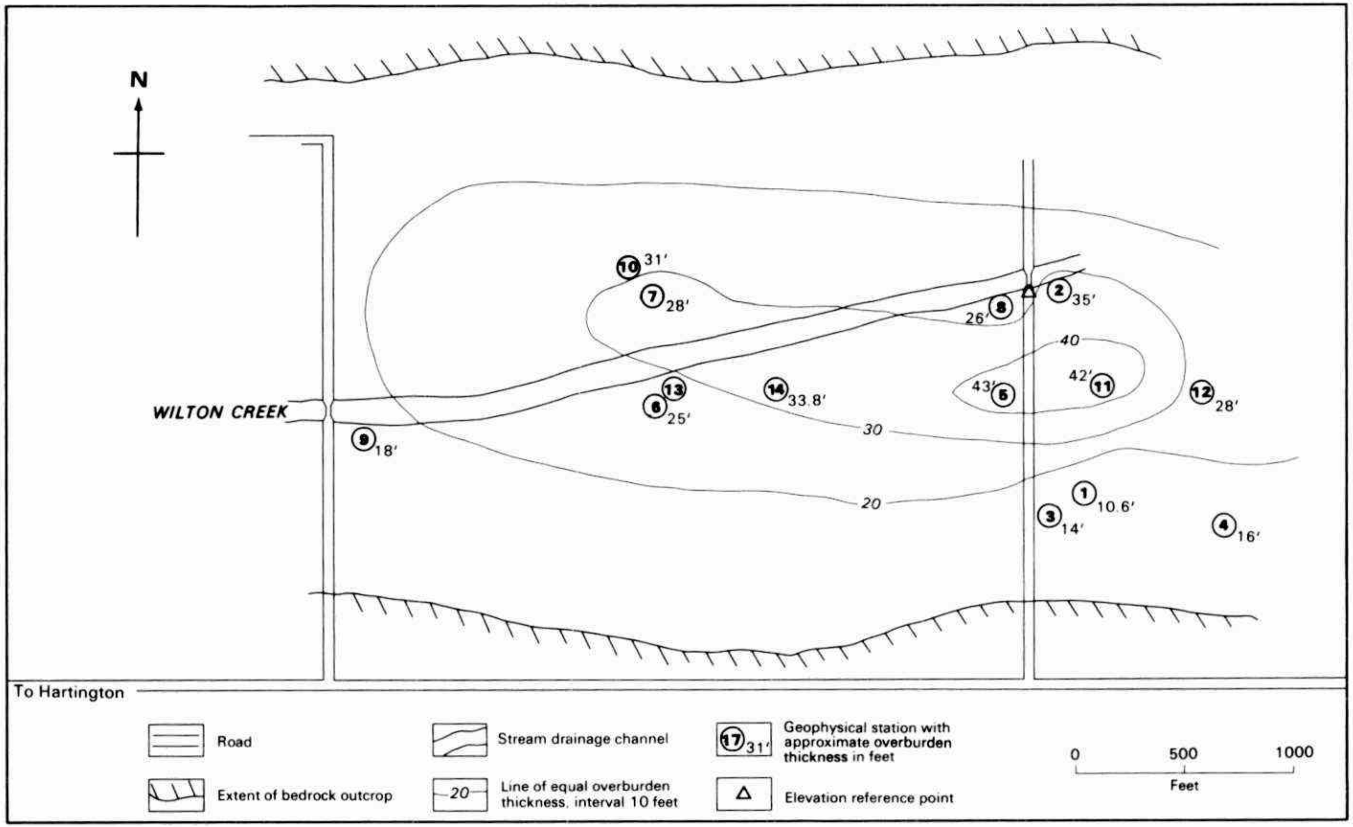

N
WILTON CREEK
To Hartington
⑩ 31′
⑦ 28′
⑧ 26′
② 35′
40
42′ ⑪
43′ ⑤
⑫ 28′
⑬
⑥ 25′
⑭ 33.8′
30
⑨ 18′
20
① 10.6′
③ 14′
④ 16′
Road
Extent of bedrock outcrop
Stream drainage channel
20
Line of equal overburden thickness, interval 10 feet
⑰ 31′
Geophysical station with approximate overburden thickness in feet
Elevation reference point
0
500
1000
Feet

Figure 4. **Sand, gravel and till plug, east of Hartington.**

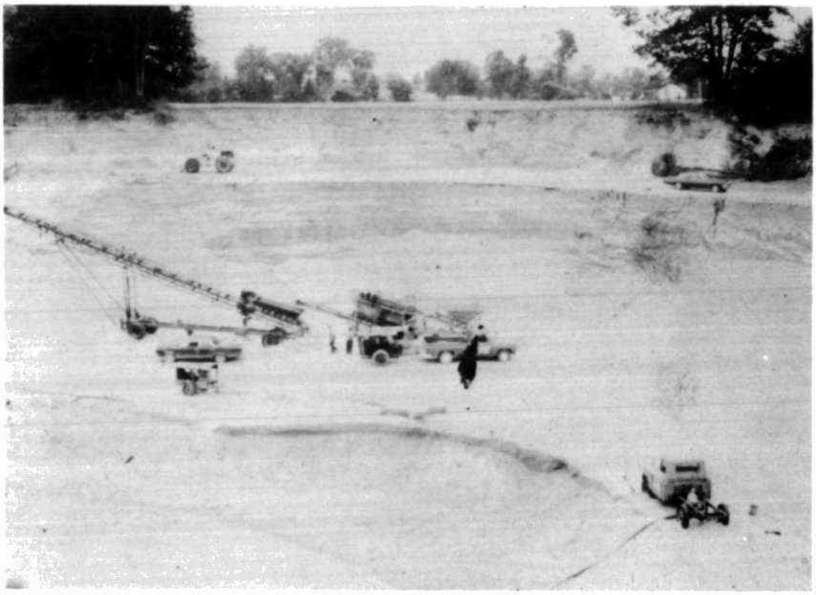


Photo 18. Large sand and gravel pit near Wilton.

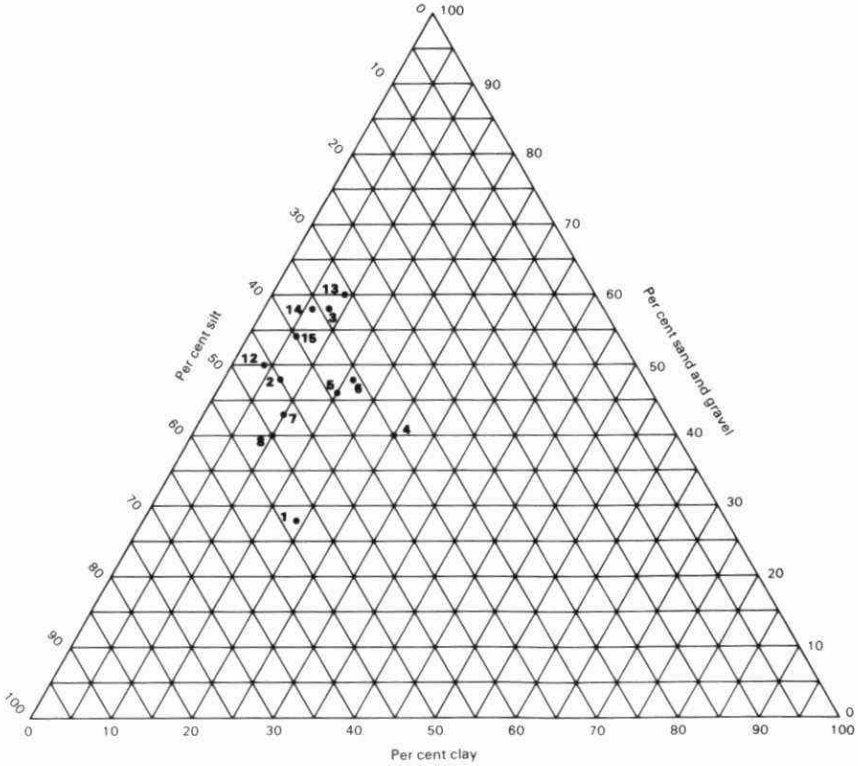


Figure 5. Triangular plot of till samples collected in the basin.

The presence of "beach remnants" on several drumlins in the south-central portion of the basin has been attributed to a brief water stand, the Lake Belleville Stage (Mirynech, 1962). A pit cut into a gravel bar running off one of these drumlins (1½ miles southeast of Morven), indicates the presence of very coarse sand and gravel, with poorly developed bedding structure. The pebbles at this locality are well rounded and are primarily limestone and Precambrian fragments. The approximate elevations for these beach remnants are 375-425 feet.

Scott (1971) suggests that the sand and gravel deposits in the creek valley near Wilton (400-foot elevation) are also beach remnants. He bases his suggestion on correlation of these deposits with other deposits in the Sydenham and Odessa areas which occur at the same elevation. Scott also found a number of clay balls in the sand and silt lenses of the Wilton deposits and attributed these to turbulent conditions. The writer feels however that this is not the case and instead postulates a subglacial origin for these deposits as is discussed previously.

RECENT DEPOSITS

The Recent deposits consist entirely of alluvium and muck. The alluvium deposits composed of silt and fine sand are very limited in area, lying adjacent to the creek. This silt and fine sand represent sediments eroded from upstream areas which have been reworked and sorted before being deposited along the stream bank.

The muck or swamp deposits are much more extensive, comprising about 6% of the total basin area (MOE, unpublished land-use survey). These deposits are confined essentially to topographic depressions, their poor drainage relating to both the impermeable underlying materials and their position relative to the local water table. These swampy areas are normally overgrown by water-tolerant plants, which upon decay add to the volume of the muck.

The occurrence of swampy areas in the valley north of Harrowsmith is in part attributed to the high water-table conditions in the glaciofluvial deposits flanking the valley sides and in part to the low permeability of the underlying Precambrian bedrock. The sands of these deposits are normally saturated year round, contributing to the maintenance of the swamps by seepage. Other swampy areas in the southern part of the basin near the mouth of the creek are saturated alluvium deposits which have been subsequently overgrown by vegetation. The areal extent of these Recent deposits is presented on Map 2.

MECHANICAL AND CARBONATE ANALYSES OF OVERBURDEN MATERIALS

Mechanical and carbonate analyses were carried out on 15 overburden samples collected within the Wilton Creek drainage basin (Map 2). In addition, mechanical analyses were carried out on six sand and gravel samples collected from observation wells at the Violet landfill site. The mechanical analyses were evaluated using the Wentworth classification.

Table 6 lists the results of these analyses along with a brief field description and the Trask (1932) sorting coefficient for each sample. Trask, considered a well sorted sediment to have a value of under 2.5. The mechanical analyses are plotted on a triangular diagram (Figure 5). This graphic plot illustrates the limited grain-size composition of the till.

Most of the samples collected south of Wilton appear to have a higher total carbonate and clay content but as the sample size was rather small no conclusions can be drawn.

TABLE 6. MECHANICAL AND CARBONATE ANALYSES OF OVERBURDEN MATERIAL

Sample Number	Field Description	Grain Size %				Sorting (Trask)	%		Total Carbonate %	Ratio Calc./Dol.
		Gravel	Sand	Silt	Clay		Calc.	Dol.		
	Samples Collected North of Wilton (sample #8 included for comparison)									
(3)	Till - sandy, reddish-brown	8	50	34	8	2.8	1.2	2.8	4.0	0.4
(8)	Till - silty, few pebbles, brown	6	34	50	10	3.2	1.2	7.0	8.2	0.2
(9)	Glaciofluvial sand - well sorted	8	92	-	-	1.7	4.4	45.8	50.2	0.1
(10)	" sand and gravel	30	70	-	-	2.1	8.2	39.8	48.0	0.2
(11)	" sand and gravel	36	64	-	-	2.1	22.6	18.6	41.4	1.2
(12)	Till - sandy, silty, few pebbles	-	50	-	4	2.0	0.8	1.6	2.4	0.5
(15)	Till - sandy, brown	10	44	40	6	2.8	1.2	2.2	3.4	0.5
	Samples Collected South of Wilton									
(1)	Till - sandy, many pebbles, compact, grey	3	25	53	19	3.2	10.8	20.0	30.0	0.5
(2)	Till - sandy, silty, brown	6	42	45	7	2.4	21.0	18.0	39.3	1.1
(4)	Till - many pebbles, compact, gray (upper till layer)	11	29	35	25	5.7	22.0	19.0	41.0	1.2
(5)	Till - many pebbles, compact, reddish-brown (middle till layer)	13	33	39	15	5.5	15.2	17.6	32.8	0.9
(6)	Till - sandy pebbles, compact, brown (lower till layer)	9	39	36	16	4.2	18.2	17.2	35.4	1.1
(7)	Till - sandy, silty, brown	6	37	47	10	2.6	15.6	20.2	35.8	0.8
(13)	Till - many pebbles, compact, brown	12	48	31	9	4.2	1.0	1.5	2.5	0.7
(14)	Till - sandy, brown	-	58	36	6	2.5	21.0	13.6	34.6	1.5

GLACIAL HISTORY

No overburden deposits older than the late Wisconsinan are known in the Kingston-Napanee area. The glacial history as interpreted from the stratigraphic relationships observable in the study area is summarized below.

The oldest deposits are of glaciofluvial origin, being deposited in the valley proper and along bedrock terraces flanking the valley walls. The presence of striae and grooves on the bedrock surface would suggest that earlier glacial sediments may have been present. The origin of the bedrock terraces is related to either or both glacial scour and stream processes.

A subglacial origin is postulated for the glaciofluvial sediments, deposition occurring by meltwater streams flowing along the terraces and valley floor in ice caverns. Any earlier glacial sediments are assumed to have been eroded and incorporated into the stratified sand and gravel.

With deglaciation, the waters of proglacial Lake Iroquois stood along the ice margin (Henderson, 1967). Henderson, because of the lack of Lake Iroquois beach and nearshore deposits, suggests that the ice margin may have been floated clear of the land surface by the buoyant action of the Lake Iroquois waters. The type of the deposit which would be formed would therefore be dependent on the position of the ice front relative to where deposition was occurring. The presence of interbedded glacial, glaciofluvial and glaciolacustrine sediments in the south and central portion of the valley would suggest an oscillating ice front.

The lower, glaciolacustrine clay layer in this area shows signs of being compressed, possibly by subsequent overriding by the ice front. In addition in the Violet and Wilton areas,clay balls have been found incorporated in the uppermost till near its contact with glaciolacustrine sediments.

It is assumed that the ice sheet retreated rapidly from the area and was followed by a lowering of the lake level with the opening of the St. Lawrence outlet. The single lacustrine shore feature, a gravel bar south of Morven, has been related to a brief transitory post-Iroquois Lake stage, Lake Belleville (Mirynech, 1962).

The sand and gravel plug at the head of the creek valley can be attributed to the final stages of the glacial retreat from the basin.

GROUND WATER RESOURCES

Ground water is the major source of domestic water supply in the Wilton Creek drainage basin. As such it is a valuable resource providing an inexpensive and near constant source of potable water. It is the intent of this report to evaluate this resource in terms of quantity and quality.

INSTRUMENTATION

A number of observation wells, streamflow gauging stations and meteorological stations have been established in the basin to provide geological, hydrological and climatological information. The instrumentation present in the basin and its location are shown in Map 6. Hydrologic and climatologic data have been collected on a continuous basis since 1967.

BEDROCK AND ITS HYDROGEOLOGIC CHARACTERISTICS

Physical Characteristics

The carbonate bedrock underlying most of the basin constitutes the major aquifer. Some basic assumptions inherent in the calculation of water-yielding properties of this aquifer, as based on its physical characteristics, are as follows:

Ground-water availability and quantity .... Ground-water availability and quantity is related to the number of interstitial openings in the bedrock and their degree of interconnection. The primary porosity (the natural volume of void space) of the carbonate rocks of the Simcoe Group is negligible as compared to their secondary porosity (fractures, solution channels and bedding planes). These openings, which act as interconnected conduits for ground-water flow, have been enlarged through the dissolution of $CaCO_3$ by undersaturated ground water (photos 19 and 20). Ground-water seepage from roadcuts and quarry faces in the area is confined to the above-mentioned openings and fractures. Photos 20 and 21 show winter ice accumulations as the result of ground-water seepage from bedding planes.

Well productivity .... The productivity of any specific well is in part dependent on the number of interstitial openings encountered, the amount of water available in the interstitial openings and the ability of these openings to transmit water to the well. Meinzer (1923), Lattman and Parizek (1964) and Siddiqui and Parizek (1969, 1971) concluded that wells situated on fracture traces in limestone bedrock, are considerably more productive than wells not situated in such positions. Similarly, wells in bedrock valleys are more productive then wells in bedrock upland areas. The observed variability of the productivity of wells drilled into the bedrock in different areas of the Wilton Creek basin is assumed to be related in part to variabilities in the density of fractures over the basin.

Well productivity with respect to well depth .... Summers (1972) and Landers and Turk (1973) found that the number and size of secondary openings in crystalline bedrock and the associated productivity, decrease with increasing bedrock depth. Erosional unloading, in part responsible for surface fractures, and weathering which enlarges these fractures, has a decreasing influence on the bedrock with depth. A similar examination of bedrock wells in the Wilton Creek basin supports the assumption of decreasing productivity with depth.

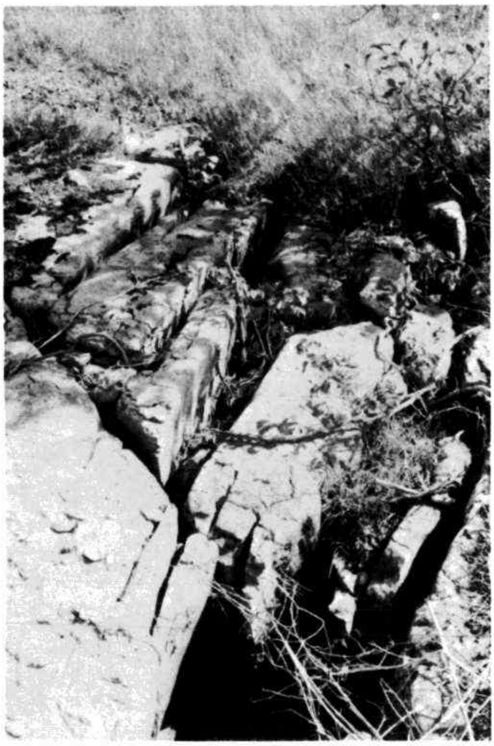


Photo 19

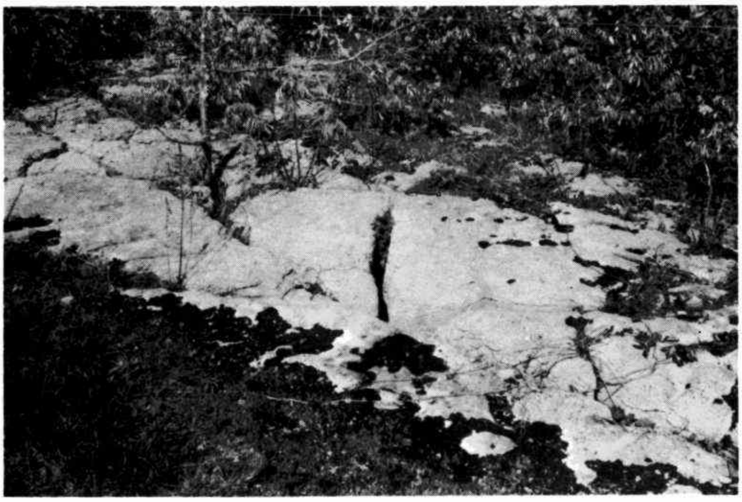


Photo 20

Photos 19 and 20. Solution-widened fractures in the Wilton Creek drainage basin.

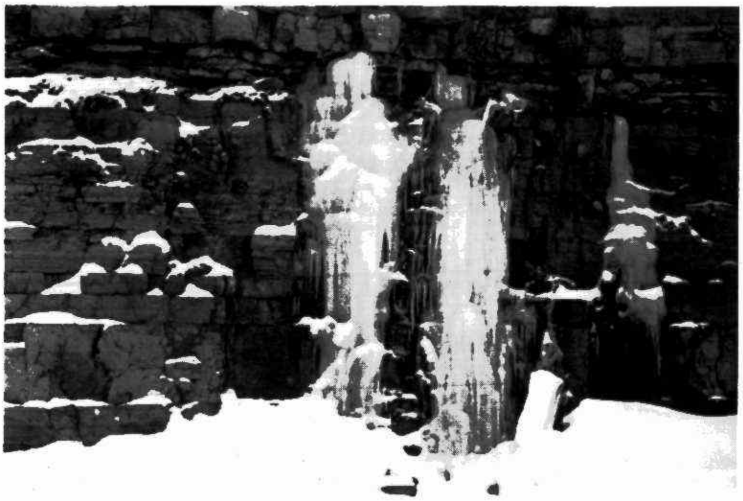


Photo 21

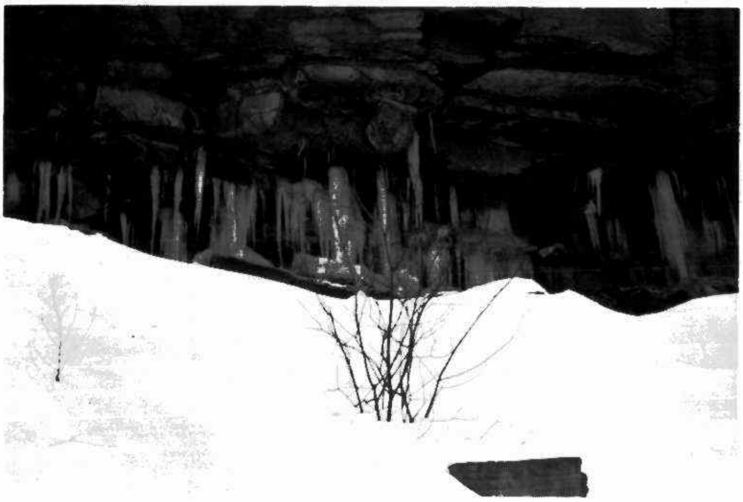


Photo 22

Photos 21 and 22. Ice accumulations as the result of seepage along bedding planes in the Wilton Creek area.

Quantitative Characteristics

The hydrogeologic properties of the bedrock can be expressed quantitatively by the coefficients of permeability, transmissibility and storage. These values were estimated for specific areas by pumping and recovery test data.

Pumping and recovery tests .... These tests, in which the effects of pumping are measured in pumped wells and in nearby observation wells, were used here in arriving at reasonable estimates of the hydraulic properties of the bedrock. The data base consists of the results of three controlled tests conducted in the basin and the results of a series of pumping tests conducted at the Lennox Power Generating Station site southeast of the study area. This information has been supplemented by specific-capacity values obtained from short-term pumping tests which are discussed later.

The Hantush and Jacob (1955), leaky artesian formula, as described by Walton (1960), was used in analyzing the pumping test data where observation-well measurements were available. The limitations imposed on this method by fracture porosity are discussed in Zeizel et al (1962). The Cooper and Jacob (1946), modified non-equilibrium formula, was used where observation-well measurements were not available. Table 7 presents the results of the pumping tests. The pumping-test data along with the method of computation are presented in Appendix II. The calculated coefficients of transmissibility range from 90-3900 Igpd/ft. A single permeability value is in the order of 100 Igpd/ft^2 and the coefficient of storage is estimated to be 4×10^{-4}.

In order to obtain a sufficient water yield to supply the needs of Service Centre E-5 located near the Highway 401 and Highway 144 intersection, it was necessary for the contractor to drill four separate wells. These wells were emplaced close together (radius of 3 feet) in an attempt to enhance fracturing of the limestone bedrock and thus effectively increasing the surrounding permeability. In addition, the last of these four wells, which is the producing well, has a larger diameter (8 inches) then the other three wells. Information on these wells is presented in Table 7. In the pumping test for the producing well (Figure 19) the fitted line was positioned in order to be compatible with the short-term character of the other tests and allow for comparison with these tests. It should be mentioned that the data indicate that a recharge boundary is reached after about 50 minutes and that a line fitted to the data points after this time period would result in a smaller drawdown and subsequently a higher transmissibility.

The results of a series of pumping tests conducted at the Lennox Power Generating Station site southeast of the study area are included for comparison. The bedrock units are similar to those encountered in the study area. It was concluded in this study (Morrison, 1971) that the transmissibility varied from well to well, depending on the degree of interconnection of the rock fractures encountered.

Specific capacities .... Specific-capacity values calculated from the results of short-term production tests conducted on domestic wells by well drillers, were used to provide information on the hydraulic properties of the bedrock aquifer. Such data are not accurate or reliable and are used in this study only to obtain a rough approximation of aquifer characteristics.

TABLE 7. PUMPING-TEST RESULTS FOR WELLS FINISHED IN THE BEDROCK AQUIFER

TEST WELLS	PUMPING RATE (WELL I. D.)	METHOD OF CALCULATION	PERMEABILITY	COEFFICIENTS OF TRANSMISSIBILITY	STORAGE
WC-7	3 Igpm (6")	Hantush & Jacob (1955)	≈100 Igpd/ft^2	≈1400 Igpd/ft	4×10^{-4}
WC-4,WC-7	3 Igpm (6")	Cooper & Jacob (1946)	NA	≈90 Igpd/ft	NA
Service Centre E5	100 Igpm (8")	Cooper & Jacob (1946)	NA	≈3900 Igpd/ft	NA
Lennox Generating Plant	8 Igpm (6")	NA	NA	700-1400 Igpd/ft	NA

NA - Not Available

Specific-capacity values are expressed as the yield of a well in gallons per minute per foot of drawdown (Igpm/ft). To obtain a uniform data base these values were adjusted to represent a common well radius of six inches and a pumping interval of one hour. In order to reduce the error involved due to losses from storage, the data were selected to ensure that the amount of water withdrawn from the well greatly exceeded that in storage in the well. This required that values for wells which went dry during pumping be discarded. No adjustments were made to compensate for well loss due to turbulent flow in the vicinity of the well.

The specific-capacity values can be used to obtain rough estimates of the transmissibility of the aquifer. Figure 6 illustrates the graphical relation between specific capacity and the coefficient of transmissibility as derived from Theis et al (1954). Generally a high specific-capacity value is an indication of a high coefficient of transmissibility. The limitations of this method are documented in Theis's paper. The estimated coefficients of transmissibility derived by this method for specified well depths are presented on Table 8.

The adjusted specific-capacity values were divided by the total uncased portion of the well in saturated bedrock, to determine the specific capacity per foot of penetration or producitivity. Productivity-frequency graphs were prepared from these data by the method attributed to Kimball by Zeizel et al (1962). This method assumes that the sample is log normally distributed. These graphs were used to examine the relationship between well yields and the following controls:

1. wells finished within specific depth intervals in the bedrock,
2. wells finished in bedrock having different lithologies,
3. wells finished in either bedrock upland areas or bedrock valleys.

The probable range of productivity for the different areas and depth intervals within the basin can be estimated from these graphs. The slope of the lines fitted to the plotted observation points is a function of the range in productivity. The steeper the line the wider is the range. Similarily the higher the position of the line on the graph the greater the productivity.

The productivity-frequency graphs for wells finished within the 0-50-foot, 50.1-100-foot and the >100.1-foot depth intervals are illustrated in figures 7, 8 and 9. In these graphs, the productivity data have been arbitrarily divided into three groups from northwest to southwest-the Township of Portland, the Township of Ernestown and the townships of North and South Fredricksburgh. These groupings roughly coincide with changes in the bedrock lithology at the surface, older units outcropping in the northeast and younger units outcropping in the southwest (Map 1). Because the bedrock units dip to the southwest, the unit encountered within a specific depth interval in one township will not necessarily be the same as that encountered within the same depth interval in the other townships. Very few wells in the townships of North and South Fredericksburgh were completed to a depth of >100.1 feet. The limited size of the well population precluded the preparation of a graph for this depth interval.

In the Township of Portland, wells completed to a depth of >100.1 feet are finished in either Precambrian or Paleozoic bedrock depending on the well location.

In order to compare the productivities of wells finished in different bedrock units these wells are grouped by the unit in which they are finished. The productivity-frequency graphs illustrated in Figure 9 present the results of this grouping. The productivity-frequency graphs illustrated in Figure 10 compare the productivity of wells finished in the bedrock valley and upland areas.

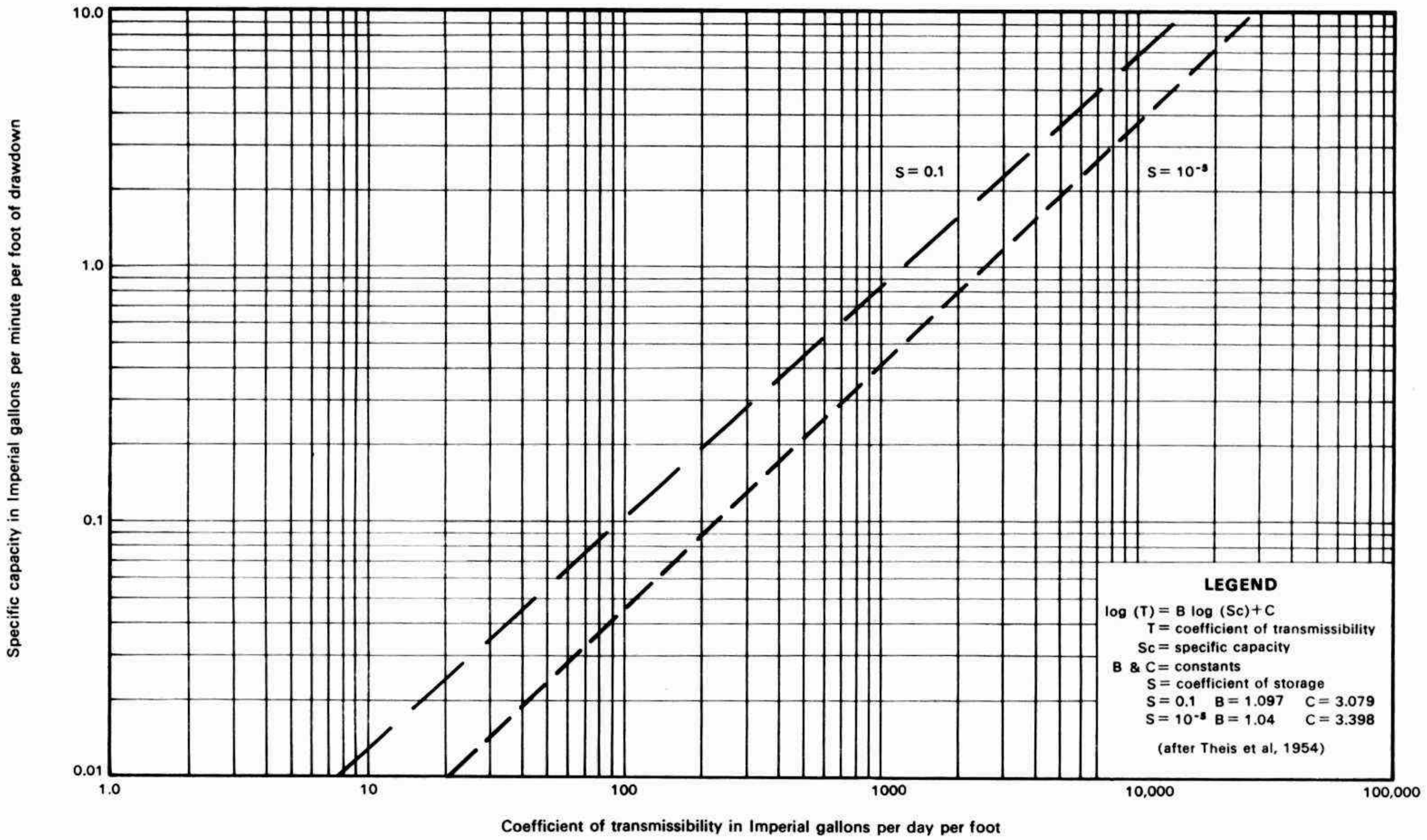


Figure 6. Relationship between specific capacity and the coefficient of transmissibility.

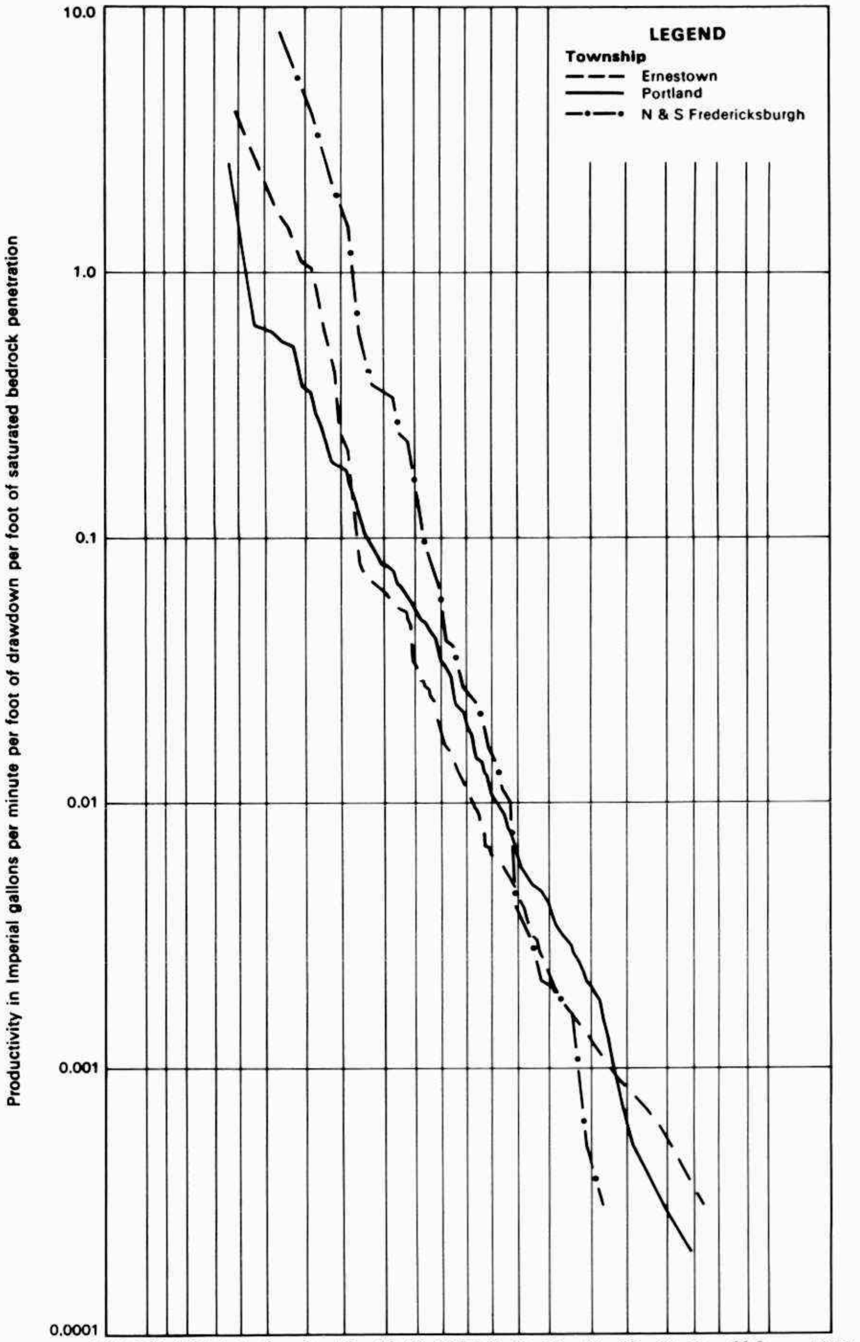


Figure 7. Productivity-frequency graphs for bedrock wells completed in the <50 foot depth interval.

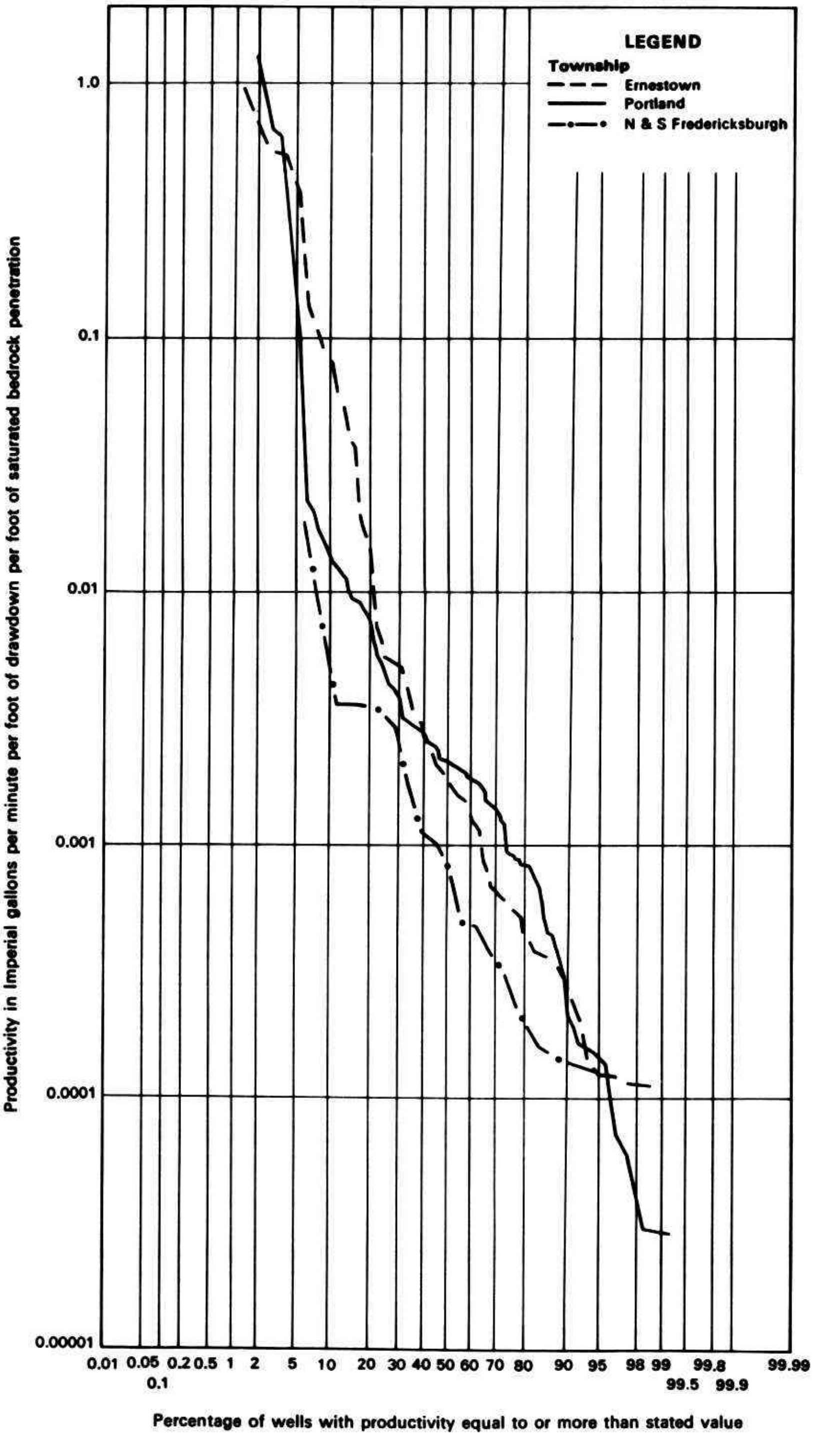


Figure 8. Productivity-frequency graphs for bedrock wells completed in the 50.1-100 foot depth interval.

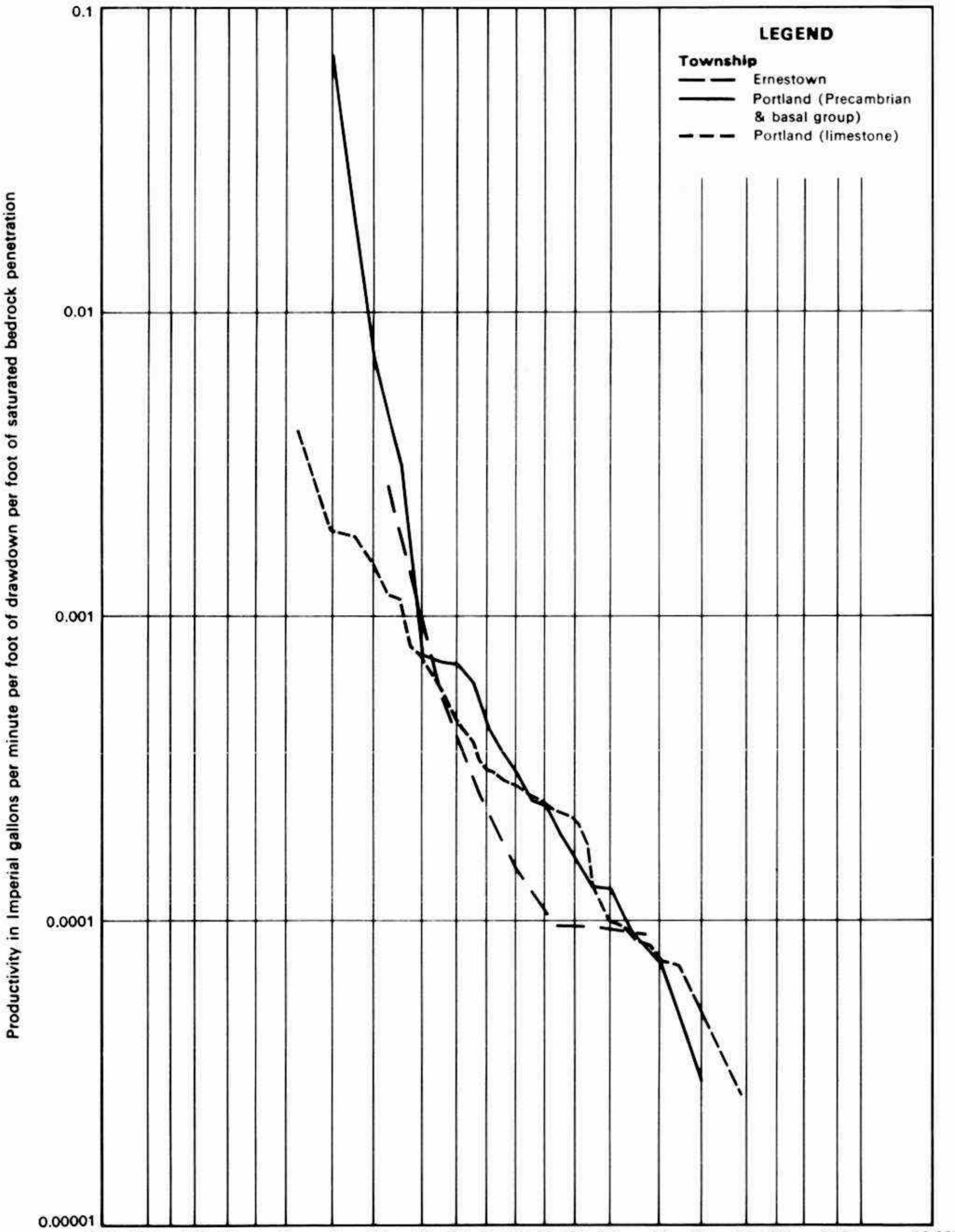


Figure 9. Productivity-frequency graphs for bedrock wells completed in the >100.1 foot depth interval.

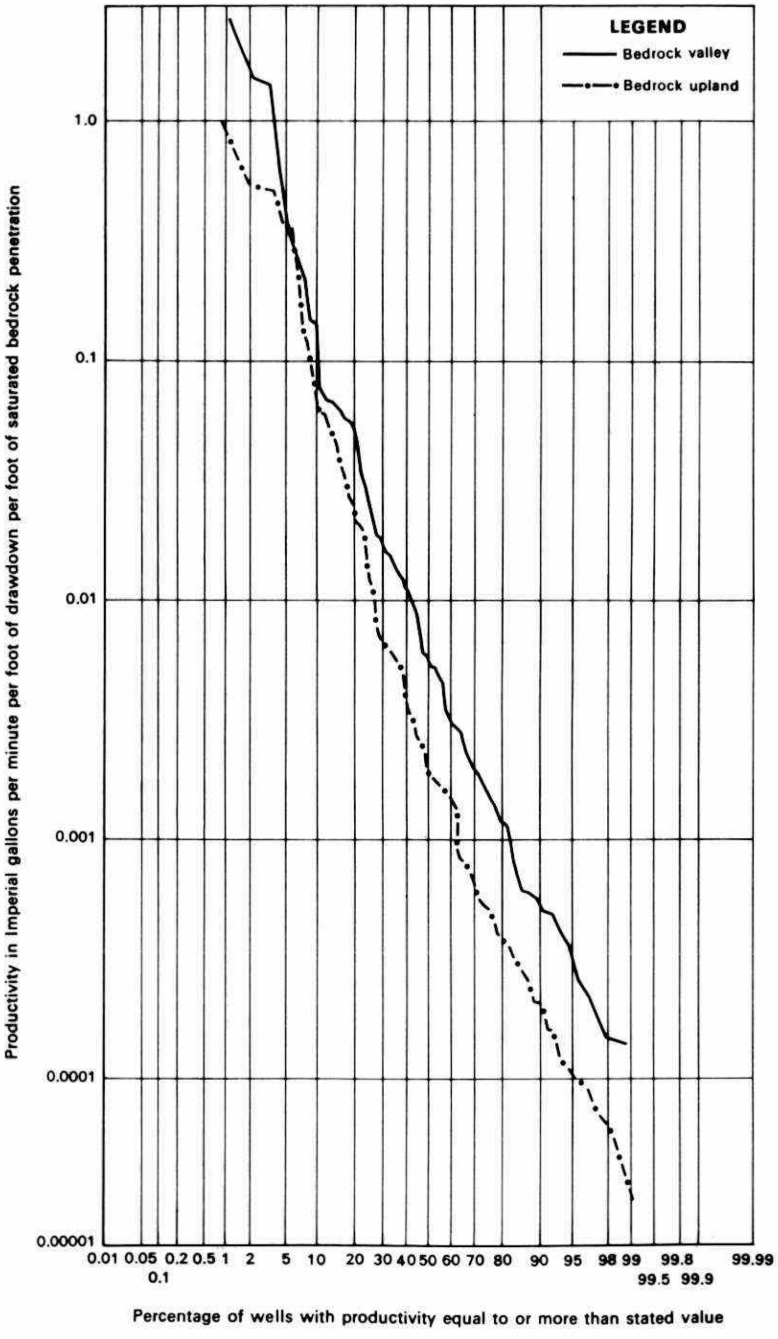


Figure 10. Productivity-frequency graphs for wells finished in bedrock valleys and uplands.

TABLE 8. TRANSMISSIBILITIES ESTIMATED FROM SPECIFIC-CAPACITY DATA FOR WATER WELLS

Range of Penetration (ft)	Calculated Mean Specific Capacities	Total Number of wells	% of Total wells	Estimated Transmissibility from Graph (Figure 6)	
Carbonate Bedrock					
0-25	1.39	70	12.96	3,600	Igpd/ft
25.1-50	1.14	195	36.11	3,000	"
50.1-75	0.43	144	26.67	1,075	"
75.1-100	1.41*	65*	12.04	3,650	"
	0.46	63		1,150	"
100.1-100	0.58**	28**	5.18	1,450	"
	0.07	27		160	"
125.1-150	0.075	24	4.44	170	"
150.1+	0.084	14	2.59	190	"
Average for Bedrock Wells	0.912	(Total) 540	(Total) 99.99	2,300	"
Average for Overburden Wells	1.18	27		1,400	"
Average for Overburden and Bedrock Wells Combined	0.924	(Total) 567		2,400	"

* Two anomalous samples (45.6 and 53.17 Igpm/ft)

** One anomalous sample (14.28 Igpm/ft)

The number, minimum, maximum, geometric mean and the median values of productivity for wells situated in different hydrogeological settings are presented in Table 9. These data were obtained from the productivity-frequency graphs and the statistical treatment of the productivity values within the categories. The following trends are apparent from an examination of the data presented in the graphs and on Table 9:

1. The Productivity of wells finished in the same townships (same area) decreases with increasing well depth. In other words, shallow wells appear to be on the whole more productive then deep wells.
2. The productivity of wells finished in the bedrock valley are greater than those in the bedrock uplands. A similar study by Siddiqui and Parizek (1971), found this relationship to hold true for carbonate rocks in central Pennsylvania. They attributed the higher productivity in wells finished in the bedrock valleys to a greater concentration of fractures in the valleys. It is suggested here that another factor for the higher productivity found in the Wilton Creek basin may result from the fact that because the water level is much closer to the ground surface in the valley than in upland areas, the completed depth of the wells finished in the valley would on a whole be less than that in the uplands area.
3. The productivity variations of wells finished at set depth intervals in areas having different lithologies are not readily apparent.

The Kruskal-Wallis nonparametric statistical test as described by Siddiqui and Parizek (1972) was applied to the productivity data in order to determine whether the observed differences in well productivities for areas having different bedrock lithologies are significant or random. The results of this test are presented on Table 10, the statistic used (H) is defined by the following formula:

$$H = \frac{12}{N\ (N+1)} \sum_{j=1}^{k} \frac{R_j^{\ 2}}{nj} - 3(N+1)$$

where:

k = number of samples,
n_j = number of observations in the j th sample,
N = Snj, the total number of observations,
R_j = sum of the ranks in the jth sample (column),
$\sum_{j=1}^{k}$ = sum over the k samples (columns),

For $nj>5$, as is the case, H is distributed approximately as chi square (x^2) with degrees of freedom (df) = (k^{-1}).

The mull hypothesis to be tested is that there is no significant difference in the productivities of wells finished within areas of different bedrock lithologies. The alternate hypothesis is that the productivities are significantly different. Setting a significance limit of $\alpha = 0.05$ with the degrees of freedom (df) = 2, the significance level for chi square corresponding to H is 5.991. All calculated values of H which are larger than 5.991 indicate that the observed differences in productivities are significant. Those values smaller then 5.991 indicate that the differences are random or not significant. Based on this statistic (Table 10), the productivities of wells in the three

TABLE 9. PRODUCTIVITY VALUES (IGPM/FT/FT) OF WELLS COMPLETED IN DIFFERENT HYDROGEOLOGICAL SETTINGS

	n	minimum	maximum	median	geometric mean
Bedrock wells finished within specified depth intervals					
<50.0 Feet	272	2.0×10^{-4}	8.0	NA	1.7×10^{-1}
50.1 - 100.0 Feet	213	2.9×10^{-5}	1.3	NA	2.9×10^{-2}
>100.1 Feet	66	2.7×10^{-5}	7.1×10^{-2}	NA	1.7×10^{-3}
Wells finished in specific rock types					
Verulam Fm. - Bobcaygeon Fm. (N.S. Fredricksburg, <50.0')	31	3.0×10^{-4}	8.0	2.7×10^{-2}	5.9×10^{-1}
Bobcaygeon Fm. - Gull River Fm., Mbrs.D,C,B (N.S. Fredricksburgh, 50.1-100.0')	17	1.3×10^{-4}	1.9×10^{-2}	8.0×10^{-4}	2.3×10^{-3}
Gull River Fm., Mbrs. D,C,B upper (Ernestown, <50.0')	110	3.0×10^{-2}	4.1	1.1×10^{-2}	1.5×10^{-1}
Gull River Fm., Mbr. B lower, Mbr. A upper & middle (Ernestown, 50.1-100.0')	77	1.1×10^{-4}	9.6×10^{-1}	1.8×10^{-3}	4.1×10^{-2}
Gull River Fm., Mbr. B lower, Mbr. A upper & middle (Portland, <50.0')	131	2.0×10^{-4}	2.6	1.9×10^{-2}	8.2×10^{-2}
Gull River Fm., Mbr. A middle & lower (Ernestown, >100.1')	7	9.0×10^{-5}	2.7×10^{-3}	1.5×10^{-4}	5.6×10^{-4}
Gull River Fm., Mbr. A middle & lower (Portland, 50.1-100.0')	118	2.9×10^{-5}	1.3	2.1×10^{-3}	2.6×10^{-2}
Gull River Fm., Mbr. A middle & lower (Portland, >100.1')	40	2.7×10^{-5}	4.1×10^{-3}	2.8×10^{-4}	5.3×10^{-3}
Shadow Lake Fm.,- Potsdam Fm. - Precambrian (Portland, >100.1')	19	3.0×10^{-5}	7.1×10^{-2}	3.1×10^{-4}	4.5×10^{-3}
Wells finished in bedrock uplands and bedrock valleys					
Bedrock Uplands	96	3.1×10^{-5}	9.9×10^{-1}	1.9×10^{-3}	4.3×10^{-2}
Bedrock Valleys	79	1.4×10^{-4}	2.6	5.5×10^{-3}	9.3×10^{-2}

NA - not available

TABLE 10. KRUSKAL-WALLIS ONE-WAY ANALYSIS OF VARIANCE FOR THE SPECIFIED PARAMETERS

Parameters Examined	Degree of Freedom	Calculated H	Significance Level 2 x 0.05	Variation Significance
For wells grouped by Townships				
Finished in <50.0 foot range	2	7.26	5.991	Significant
Finished in 50.1-100 foot range	2	7.22	5.991	Significant
Finished in >100.1 foot range	2	0.99	5.991	Not Significar
Wells finished in the bedrock valley as compared to bedrock uplands	1	8.55	3.841	Significant

townships are significantly different for the 0-50 foot and 50.1-100 foot ranges of bedrock penetration. There is no significant difference in wells finished in the >100.1 foot range even though the bedrock lithologies vary from Precambrian rocks, to the 'basal group' clastics to limestones. Therefore the null hypothesis is rejected for the wells finished in the 0-50 foot and 50.1-100 foot ranges and accepted for the >100.1 foot range.

A Kruskal-Wallis test, conducted on the productivities of the upland and valley wells, also indicates that there is significant difference in productivity, $d_f=1$, significance level 3.841 (Table 10).

OVERBURDEN DEPOSITS AND THEIR HYDROGEOLOGIC CHARACTERISTICS

The sparseness of overburden in the drainage basin is illustrated by the overburden (isopach) thickness map (Map 3). The average thickness of the overburden, with the exception of local sand and gravel deposits in the Wilton Creek valley proper, is in the order of 3-5 feet (Photo 24).

The till and lacustrine deposits act as a low-permeable mantle, creating semi-confined aquifer conditions where they overlie glaciofluvial sediments and bedrock. The sands and gravels of the glaciofluvial deposits locally constitute favourable aquifers; however, their thickness and areal extent are too small to yield anything but small domestic water supplies. The areal distribution of these glaciofluvial deposits is presented in Map 4. From the water-well records, the maximum thickness of these deposits is about 90 feet, while the average thickness is about 20 feet. Photo 25 shows de-watering operations in a gravel pit near Wilton.

The mean specific-capacity value (1.18 Igpm/ft) for 27 overburden wells was used to estimate a mean coefficient of transmissibility of 1,400 Igpd/ft, with a coefficient of storage in the order of 0.1 (Figure 11).

Estimates of the permeabilities of various glaciofluvial sands exposed in sand pits in the Wilton bedrock valley were obtained using Hazen's empirical relationship between grain-size distribution and permeability (Hough, 1957). The results are listed below:

Sample	Location	10% Finer (mm)	Permeability (Igpd/ft^2)
9	East of Hartington	2.3×10^{-1}	550
10	East of Hartington	3.5×10^{-1}	850
11	East of Hartington	4.6×10^{-1}	1000
Well #5(10-15')	Violet Landfill	1.3×10^{-1}	400
Well #6(12-13')	Violet Landfill	5.5×10^{-1}	3000
Well #7(6-8')	Violet Landfill	1.65×10^{-1}	450
Well (12')	Violet Landfill	2.6×10^{-1}	600
Well (22-23')	Violet Landfill	2.1×10^{-1}	510
Well (28-30')	Violet Landfill	1.2×10^{-1}	375

Mean = 860 Igpd/ft^2

Photo 23. Sparse overburden in the Violet area.

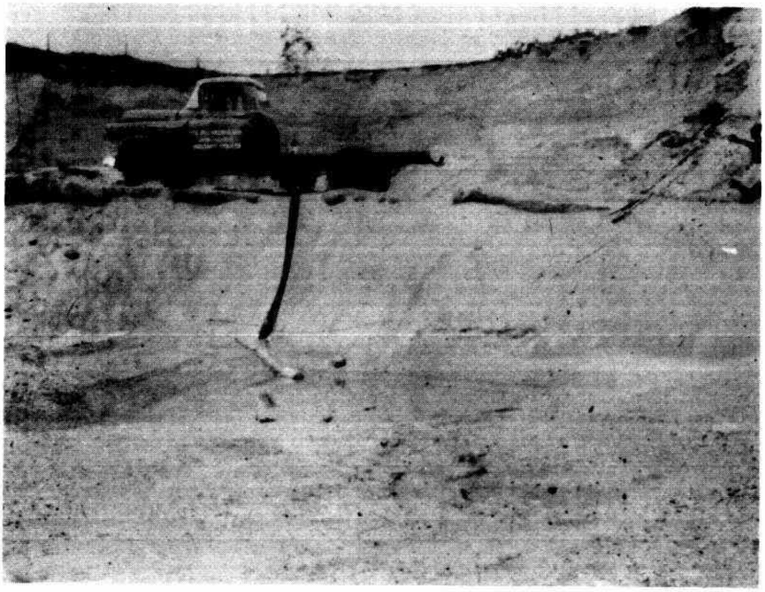


Photo 24. Dewatering of saturated sand and gravel in a pit near Wilton.

GROUND WATER MOVEMENT

Ground water moves continuously through the hydrogeological environment. The rate of movement is dependent on the local hydraulic gradient and the hydraulic properties of the medium. The theory of ground-water movement within the three-dimensional domain has been described in detail by Hubbert (1940), Toth (1962, 1963) and Freeze and Witherspoon (1966, 1967).

In theory, ground-water movement is confined on all sides by imaginary, impermeable boundaries. In the Wilton Creek basin, the lateral boundaries as established from water-well records appear to coincide with the drainage divide. The lower boundary underlying the domain is set at a horizon where flow approaches static conditions. This horizon is arbitrarily set at the elevation of the streambed near the mouth of Wilton Creek (≈200 foot m.s.l.) and is extrapolated under the rest of the basin. This presupposes no underflow into nor out of the domain and that all ground-water discharge is into the stream. The upper boundary is represented by the water table, the upper surface of the zone of saturation.

Hydraulic Potential

The hydraulic potential of the ground-water at any point in the domain is defined by Hubbert (1940) as follows:

$$\Phi = g z + (p_1 - p_o)/\rho$$

where:

Φ = hydraulic potential at any point in the domain,
g = acceleration due to gravity,
z = elevation at the given point above a standard horizontal datum,
p_o = atmospheric pressure, p_1 = pressure at the given point,
ρ = density of water.

The hydraulic head (Φ) or level to which the ground-water will rise in a well or piezometer (measured in feet of water above a standard datum), equals the hydraulic potential divided by the constant (g). The water-level map (Map 5), which illustrates the relative values of hydraulic head as measured in various water wells in the basin, can be used to approximate the horizontal direction of ground-water movement (horizontal flow vector). Ground-water movement is from areas of high hydraulic head on this map to areas of low head, in a direction perpendicular to the water-level contours. From the configuration of the water-level contours, it is evident that the local topographic relief has a strong influence on the hydraulic head, the water-level map being a subdued replica of the topographic base map. Ground-water movement is directed down the local topographic slope and in a more general pattern from the top end and divides of the basin to the mouth.

The vertical direction of ground-water movement and the magnitude of the hydraulic gradient for a specific location can be established by measuring the hydraulic head in two or more piezometers which are placed side by side and set at different depths. In recharge areas the measured hydraulic head decreases as the piezometer depth increases. In discharges areas, the reverse holds true. Hydrographs for two piezometer nests, one (WC-1) located in the northern and the other (WC-8) in the southern reaches of the basin are presented in figures 11 and 12.

Piezometer nest WC-1 has two piezometers; one set at 25 feet and the other set at 63 feet. Based on the measurements for 1968 to 1973, ground-water movement is vertically downward. This suggests that this portion of the basin acts as a recharge area. Piezometer nest WC-8 also has two piezometers; one set at 29 feet and the other at 176 feet. Based on the measurements, ground-water movement is vertically upward as is characteristic of a discharge area.

Hydraulic Properties of the Medium

The hydraulic properties of the overburden and bedrock aquifers have been discussed previously. A crude estimate for an average coefficient of transmissibility for the basin is obtainable by applying Darcy's Law as follows:

$$Q = 2\ TIL$$

where:

Q = mean baseflow discharge for the period under investigation (1967-74) which is approximated as 12.7 cfs,

T = average transmissibility,

I = average water - table slope perpendicular to the stream which is estimated as 0.02 feet/foot,

L = creek length north of the recording station which is approximately 21.5 miles. (Length is multiplied by 2 to simulate flow into the stream from both sides.)

The coefficient of transmissibility thus calculated is 1360 Igpd/ft^2. This value compares favourably with values estimated from pumping tests (Table 7) and specific-capacity data (Table 8).

WATER LEVEL FLUCTUATIONS

Water-level measurements have been collected at regular intervals from the eight MOE - IHD observation wells in the basin. The water levels, which fluctuate continually, reflect the dynamic nature of the ground-water storage in the basin. This fluctuation is related to changes in the ratio of ground-water recharge to discharge. A rise in the ground-water level implies that recharge exceeds discharge and water is taken into storage. A decline in the ground-water level implies that the reverse holds true.

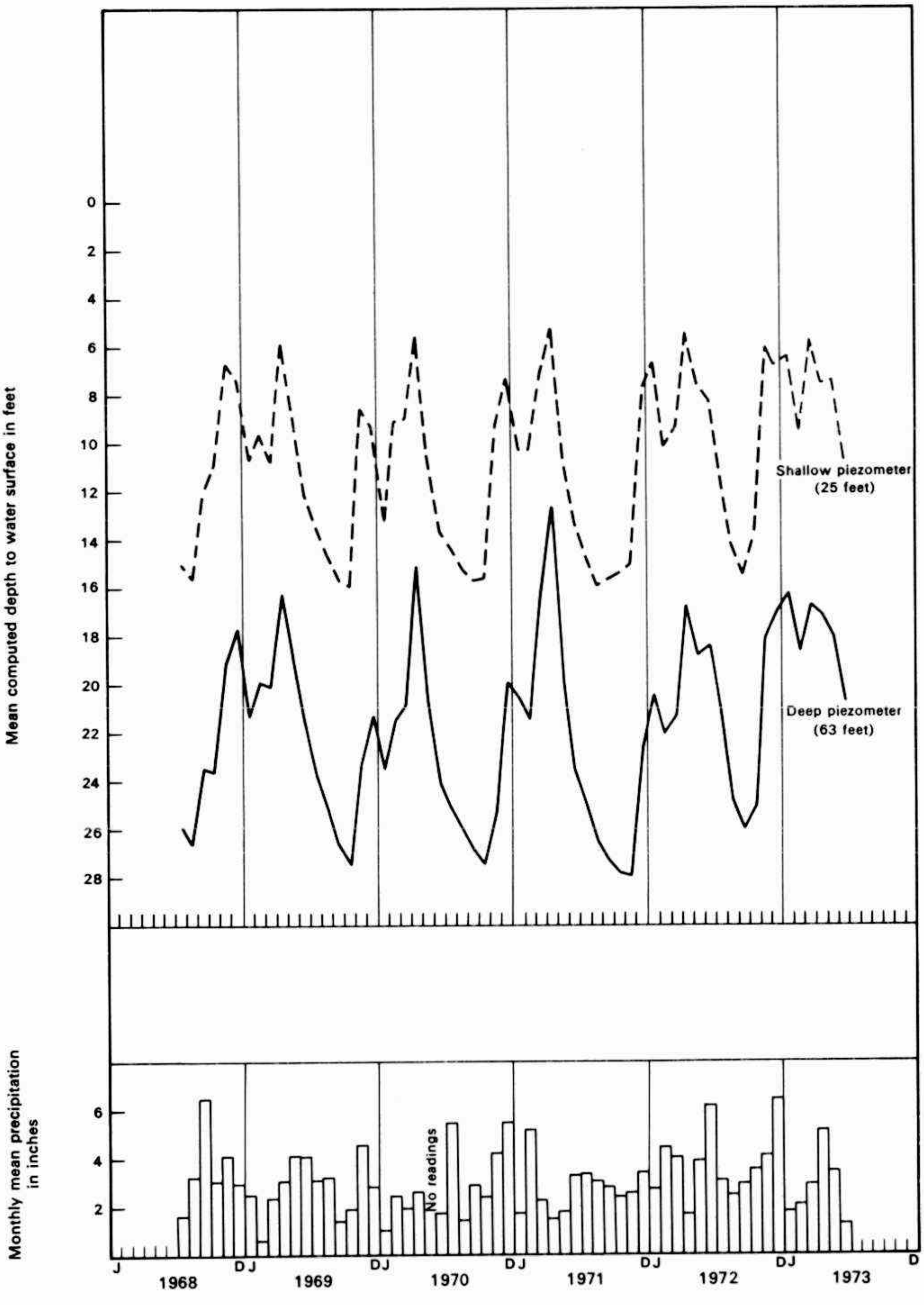


Figure 11. Hydrograph for MOE observation well WC-1 and the precipitation record for Hartington for 1968 to 1973.

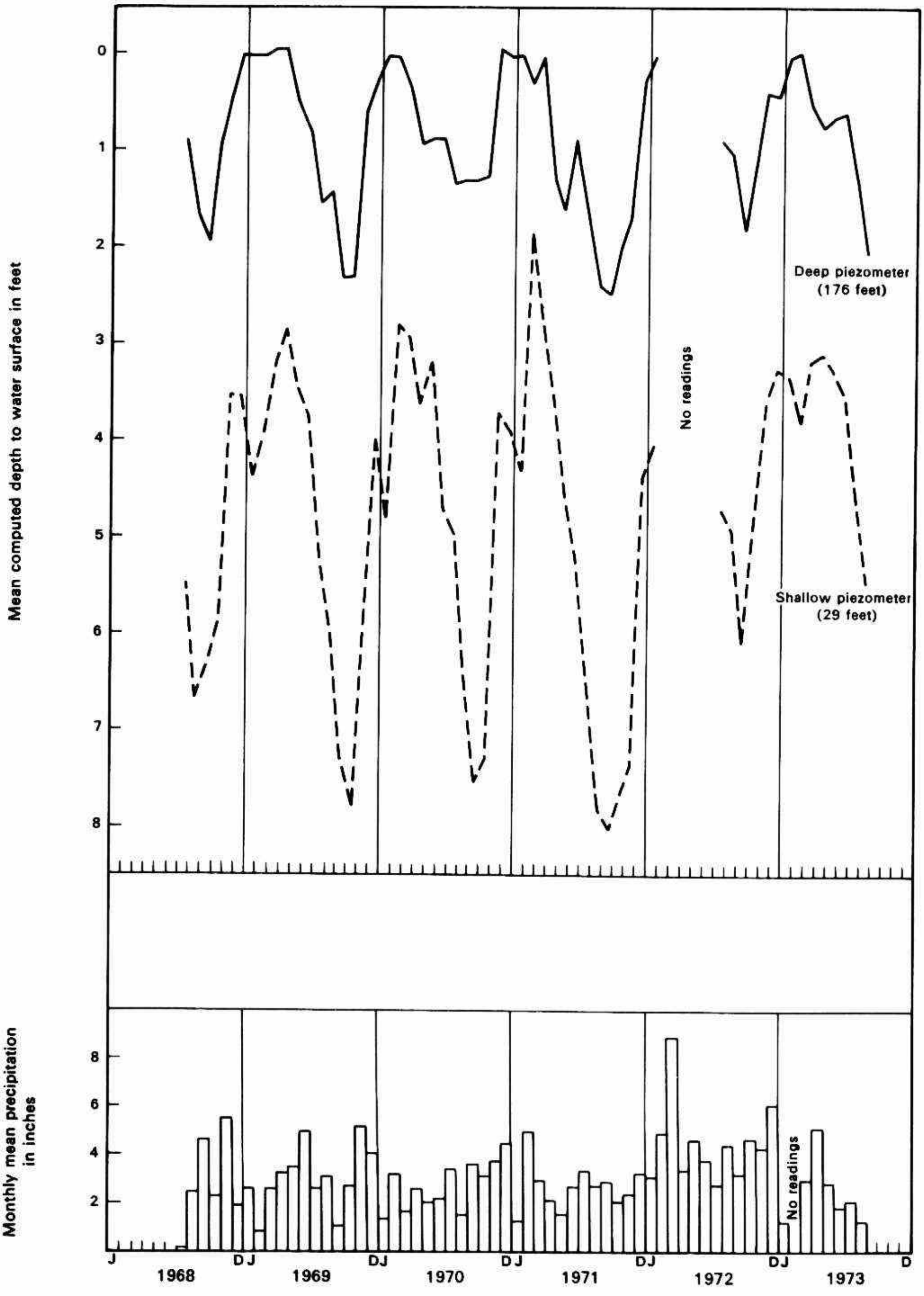


Figure 12. Hydrograph for MOE observation well WC-8 and the precipitation record for Morven for 1968 to 1973.

TABLE 11. SUMMARY OF WATER-LEVEL FLUCTUATIONS IN THE BASIN

Well Number	Piezometer or well Depth	1967-68		1968-69		1969-70		1970-71		1971-72		1972-73	
		Max. and Min.	Var.	Max. and Min.	Var.	Max. and Min.	Var.	Max. and Min.	Var.	Max. and Min.	Var.	Max. and Min.	Var.
WC-1 A	25	5.5-15.7	10.2	4.9-15.8	10.9	4.5-16.0	11.5	3.1-16.7	13.6	5.1-15.8	10.7	4.7-15.0	10.3
WC-1 B	63	18.0-27.5	9.5	11.9-26.9	14.9	12.2-27.7	15.5	8.6-28.2	19.6	16.7-28.4	11.7	13.7-26.3	12.6
WC-2	78	28.1-55.6	27.5	26.1-51.8	25.7	28.6-57.5	28.9	23.8-57.8	34.0	25.3-55.5	30.1	27.6-57.5	29.9
WC-3 A	178	21.1-22.9	1.8	19.3-24.0	4.7	24.3-31.7	7.4	23.4-29.7	6.3	25.5-29.1*		23.0-28.8*	
B	118	26.7-33.6	6.9	20.4-36.9	16.5	23.8-32.1	8.3	24.1-32.7	8.6	28.9-32.7	3.8	25.0-31.1	6.1
C	46	18.9-35.5	6.6	7.7-36.1	28.4	11.3-36.2	25.9	6.1-37.1	31.0	16.8-35.5	18.7	7.4-34.3	26.9
D	29	11.2-26.7	15.5	5.8-28.5	22.7	8.7-29.1	20.4	5.7-33.0	27.3	12.9-33.9	22.0	6.4-22.6	16.2
WC-4	44					2.3-9.5	7.3	4.6-8.1*		3.6-8.5*		3.3- 8.7	5.4
WC-5	103	4.1-20.4	16.3	3.4-20.6	17.2	2.9-20.9	18.0	3.4-20.8	17.4	3.7-17.2	13.5	3.5-20.5	17.0
WC-6 (1)C	85	33.6-37.0	3.4	29.6-37.7	8.1	29.0-36.7	7.7	29.3-36.9	7.6	33.1-36.9	3.8	28.9-35.6	6.7
(2)B	45	19.6-30.9	11.3	18.0-23.4	5.4	16.9-22.4	5.5	18.0-23.6	5.6	20.8-24.3	3.5	18.0-22.1	4.1
(3)A	13	10.1-12.0	1.9	9.9-12.9	3.0	10.1-11.9	1.8	10.3-11.8	1.5	10.4-12.0	1.6	9.3-11.2	1.9
WC-7	23	13.0-19.0	6.0	12.3-18.8	6.5	12.1-18.5	6.4	8.3-16.9	8.6	8.1-16.1	8.0	8.0-15.1	7.1
WC-8 FCS	176	1.0- 2.6	1.6	0.1- 2.5	2.4	0.1- 3.1	3.0	F- 2.6	2.6+	1.6- 2.3	0.7	0.3- 5.7	5.4
RDS	29	5.6- 7.1	1.5	2.4- 7.6	5.2	2.1- 7.9	5.8	1.7- 8.3	6.4	2.95- 7.7	4.75	0.3- 6.1	5.8

* Partial Record

F = Flowing

The fluctuations of the water level at two locations in the basin are represented graphically by hydrographs for the observation wells in figure 11 and 12. These hydrographs indicate that the water levels fluctuate seasonally, with lows occurring in the late summer and highes during the spring melt. Similarly both the magnitude of the fluctuations and the direction of flow, as represented by the hydraulic head difference in closely spaced piezometers, varies with location. A summary of the seasonal water-level fluctuations is presented in Table 11 for different observation wells in the basin.

HYDROLOGIC BUDGET

The hydrologic budget, a quantitative statement of the balance between recharge and discharge for a set interval of time, can be expressed mathematically by the following equation:

$$P = R_g + R_s + ET \pm U \pm S$$

where:

P = total precipitation,
R_g = ground-water runoff or baseflow
R_s = surface runoff,
$R_g + R_s = R_t$ = total runoff
ET = evapotranspiration,
U = subsurface underflow,
S = change in storage (surface, soil moisture, ground water)
$S = (S_s + S_{sm} + S_g)$

This equation is calculated by estimating and measuring the various parameters which affect its solution. Precipitation and total runoff are measured directly, the surface and ground-water runoff components and the evapotranspiration are estimated. It is assumed from the water-level map (Map 5) that the subsurface underflow into and out of the basin is negligable. Similarly for the period under investigation (1967-68 to 1973-74 water years) it is assumed that there is no appreciable change in storage. The equation can therefore be simplified to:

$$P = R_g + R_s + ET$$

Precipitation

Precipitation which includes rain, snow and dew is measured directly at the meteorological stations in and around the basin. Precipitation and temperature records for these stations were generally found to be erratic; however, two stations (Hartington IHD and Morven IHD) had sufficient data to cover the seven-year period. Mean monthly precipitation and temperature data tabulated for these two stations are presented in Table 12.

Runoff

Runoff is that portion of precipitation which appears in surface streams and is measurable by water-level gauges installed on the stream. Data from the hydrometric station 2HM-004, near Morven, were used to approximate the total stream runoff from the basin.

The ground-water runoff component or baseflow, was estimated from the hydrometric records by the method attributed to Wundt by Meyboom (1967). Wundt's method of analysis assumes that the monthly minimum streamflow is taken as a measure of baseflow. The annual baseflow for each water year (Table 12) is the mean monthly minimum flow for that year. This simplistic method provides a means of applying a statistical rather than an arbitrary approach towards baseflow analysis.

Evapotranspiration

It is necessary to measure evapotranspiration by indirect methods. Two different methods were incorporated into this report, the Munson-Index Method (ASCE, 1966) and the Water Balance Equation or Indirect Method.

The Munson-Index Method is an empirical method in which the potential evapotranspiration is taken directly from a table on which monthly mean temperatures are compared to potential evapotranspiration values. This method assumes that there is no evapotranspiration below the monthly mean temperature of 28.4°F. The empirical results are presented on Table 12.

The Indirect Method consists of solving the simplified water balance equation:

$$ET = P - R_T$$

The results are presented on Table 12.

In comparing these two methods, the results obtained by the Munson-Index Method are approximately 10% higher than those obtained by the Indirect Method. The difference in these two methods can readily be explained by the cumulative errors inherent in the estimation of the various components of the budget, and also the net changes in basin storage and underflow which were assumed to be negligible. The seven-year average values for both Munson-Index and the total calculated lake evaporation (Hartington-IHD station pan evaporation measurements) are also in close agreement (Table 12).

These methods do not take into consideration all of the factors which contribute to the actual evapotranspiration such as soil types, vegetation types, air humidity, wind velocity; however, they probably give a valid approximation.

TABLE 12. ESTIMATED ANNUAL HYDROLOGIC BUDGET OF THE WILTON CREEK DRAINAGE BASIN FOR THE INTERVAL 1967-68 AND 1973-74

Water Year	Precipitation* Inches	Temperature °F*	Total Runoff Inches	Estimated Baseflow	Baseflow as % of Total Runoff	Baseflow as % of Precipitation	Potential Evapotranspiration		
							Munson P.E. Index Method	Indirect Method	Pan. Evap. (Hartington)
1967-68	37.34 E	43.67	16.52	3.78	22.9	10.1	23.24	20.82	18.04 E
1968-69	32.78 E	43.80	19.76	4.45	22.5	13.6	22.26	13.01	22.49
1969-70	33.96	42.94	13.76	3.10	22.5	9.1	22.81	20.21	19.77 E
1970-71	36.45 E	42.97	13.32	4.67	35.1	12.8	22.36	23.13	23.72 E
1971-72	42.86	43.67	14.44	3.64	25.2	8.5	22.13	28.43	23.27
1972-73	39.40	44.89	21.84	4.68	21.0	11.9	23.62	17.57	26.83
1973-74	36.45	43.57	15.20	3.60	23.7	9.9	22.33	21.25	23.78
Average (7 Years)	37.04		16.40	3.97	24.2	10.7	22.68	20.64	22.56 E

* Average for Hartington and Morven

E Value based on some estimated daily values

HYDROCHEMISTRY

The hydrochemistry is an important consideration in the evaluation of the water resources of an area. The water quality characteristics not only dictate the suitability of the waters for use but also can be useful in estimating the general ground-water flow patterns.

As the waters move through the drainage basin they are subject to a series of continuous reactive processes which tend to change their chemical composition. These changes either contribute additional ions or remove them depending on the chemical reactions which are involved. Specific trends emerge in the hydrochemistry when viewed on either a regional or a basin-wide scale. For instance ground water in a recharge area generally has a bicarbonate character while that in a regional discharge area has a chloride character (Chebotarev, 1955). In the following sections the hydrochemistry of the basin's waters will be presented and discussed with respect to their suitability for domestic use. In addition the hydrochemical data is used to estimate general ground-water flow patterns.

Sampling Procedures and Analyses

A total of 38 water samples were collected from wells in the Wilton Creek drainage basin, from October 16-19, 1973 to establish the chemical characteristics of the ground water. In addition, one sample collected on November 16, 1973 and 14 samples collected during a water survey conducted in 1969 are included in the presentation. Both MOE observation wells and private domestic wells were sampled.

Sampling procedures varied with the type of well. The domestic wells (normally equipped with electric or hand pumps) were pumped for a five minute period of time in order to ensure fresh samples. No water samples were taken from wells where a chlorinator or water softener could not be by-passed. The observation wells and piezometers were sampled by bailing these dry where possible and then allowing them to recover prior to sampling. In a few cases, the well depth was excessive and the well could not be bailed dry. In such cases the well was bailed several times allowing the water level to recover between bailings before samples were taken.

All water samples were analysed for bicarbonate alkalinity, pH, temperature and conductivity at the time of sampling. In addition, static water levels were recorded for the MOE wells. Laboratory analyses included: calcium, magnesium, sodium, potassium, chloride, iron, bicarbonate alkalinity, sulphate, nitrate, total phosphorus, total dissolved solids, hardness and alkalinity as $CaCO_3$, (all in milligrams/litre) and pH and conductivity (micromhos per cm). The results of the water analyses are presented in Table 13 (in Appendix C).

Water samples had been taken periodically from the creek during the early stages of the IHD representative basin study, to establish background information on stream water chemistry. Table 13 present the results of these analyses for November 1968 to April 1969. Only minor variations in water quality occurred over that period.

A computer program written by Wigley (1971) and modified by J. Coward (pers. comm.) was employed to obtain mean maximum and minimum relative (ion ratios) and absolute values for different chemical constituents in the water. These results, in addition to saturation values of calcite, dolomite, gypsum and magnesite, are included in Table 15 (in Appendix C).

The saturation indices for calcite (SATCAL), dolomite (SATDOL), and gypsum (SATGYP), as defined by Wigley (1971), were determined as follows:

$$\mathrm{SATCAL} = \log(aCa^{++}\ aHCO_3^{-}\ K_{HCO_3}) - \log(aH^{+}\ K_s),$$

$$\mathrm{SATDOL} = \log(aCa^{++}\ aM_g^{++}(aHCO_3^{-})^2(K_{HCO_3})^2 - \log((aH^{+})^2\ K_d),$$

$$\mathrm{SATGYP} = \log(aCa^{++}\ aSO_4^{--}) - \log(K_g)$$

where:

aCa^{++} is the activity of the calcium in solution,

aM_g^{++} is the activity of the magnesium in solution,

aH^{+} is the activity of the hydrogen in solution,

$aHCO_3^{-}$ is the activity of the bicarbonate in solution,

aSO_4^{--} is the activity of the sulfate in solution,

K_{HCO_3}, K_s, K_d, K_g and K_m are temperature dependent equilibrium constants.

In addition Coward (pers. comm.) included the saturation index for magnesite (SATMAG) as follows:

$$\mathrm{SATMAG} = \log(aM_g^{++}\ aHCO_3^{-}\ K_{HCO_3}) - \log(aH^{+}\ K_m)$$

The saturation indices were calculated using temperature dependent equilibrium constants given by Wigley and the lab values of temperature and pH. The calculated indices of saturation are considered to be significant only if the values deviate from zero (the saturation point) by 0.4 or more (the analytical error through using lab values, J. Coward, pers. comm.). Positive values (greater then 0.4) are considered to be supersaturated while negative values (less then -0.4) are considered to be undersaturated.

The saturation indices are indicative of the ability of the water to dissolve the different mineral species such as calcite or dolomite from the aquifer materials. For example, where the ground water is undersaturated with respect to calcite the water has the potential for dissolving calcite. Conversely, where the water is saturated with calcite, calcite may be precipitated out if CO_2 is lost.

The pumpage of a well will result in a drop in aquifer pressure in the vicinity of the well. If the ground water in the vicinity of the well is saturated with calcite this drop in aquifer pressure may result in the release of CO_2 from the ground water which will then become supersaturated. Waters which are supersaturated tend to be unstable resulting in the precipitation of carbonates. Some level of supersaturation is desirable as the precipitation of carbonates coats the distribution system with a protective film reducing corrosion. Excessive supersaturation however can result in the encrustation of well screens and the precipitation of carbonates in the pore spaces of surrounding aquifers reducing well yields.

Water Quality Characteristics

The chemical constituents of ground and surface waters are largely derived from the solution of minerals in the overburden and bedrock through which the waters pass. Both the overburden which is largely derived from the local limestone bedrock and the bedrock itself, act as sources of carbonate minerals. The ground and surface waters of the Wilton Creek drainage basin possess certain chemical characteristics that are typical of waters in a carbonate terrain. As rain water percolates through the soil horizon, it dissolves large amounts of carbon dioxide forming carbonic acid. Carbonic acid is a common solvent of carbonates. Analyses of waters in a carbonate terrain are characterized by high concentrations of calcium, magnesium and bicarbonate ions resulting from the solution of calcite and dolomite. Minor chemical constituents in the waters result from the solution of other minerals in the bedrock such as gypsum, clay minerals and salts.

The three major anions, bicarbonate (HCO_3^-), sulphate (SO_4^{--}) and chloride (Cl^-) and the four cations, calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+) and potassium (K^+) are examined in this study. The chemical analyses of the water samples are listed in Table 13. The predominant cations and anions of the ground-water samples are presented diagrammatically in a Piper trilinear plot (Figure 13). Each vertex represents the 100 percent concentration level of a selected ion or group of ions. The distribution of the major anions and cations is dicussed in the next section.

The nitrate, phosphorus and iron concentrations in both the surface and the ground waters vary considerably over the basin. High nitrate and phosphorus concentrations have often been associated with well contamination from surface sources such as barnyard wastes or septic systems. These generally occur in a very localized manner. High iron concentrations in the MOE observation wells are attributed to the leaching of iron from the well casing into the surrounding ground water.

Correlation of the Hydrochemistry with the Direction of Ground Water Flow

Ground water, as it moves through the basin following infiltration, is subject to a series of reactive chemical processes which change the chemical composition of the water. These processes are discussed in considerable detail in Chebotarev (1955), Schoeller (1959) and Hem (1970). When viewed on a regional scale, certain sequential patterns can be established from hydrochemical data. One such pattern, the evolutionary sequence in chemical composition or "metamorphism" as described by Chebotarev (1955) for ground waters within a regional flow system, is as follows:

$$HCO_3^- \rightarrow HCO_3^- + Cl^- \rightarrow Cl^- + HCO_3^- \rightarrow Cl^- + SO_4^= \text{ or } SO_4^= + Cl^- \rightarrow Cl^-$$

This is normally accompanied by an increase in the total mineralization of the water. The application of Chebotarev's sequence to delineate the pattern of ground-water movement in a specific area should be used in unison with a previous understanding of the flow system(s). For example, individual water samples tend to reflect localized conditions which in a heterogeneous hydrogeological environment may be anomalous with respect to the sample's position in the flow system. The statistical treatment of several such samples may be helpful in reflecting regional and possibly basin-wide trends in hydrochemistry.

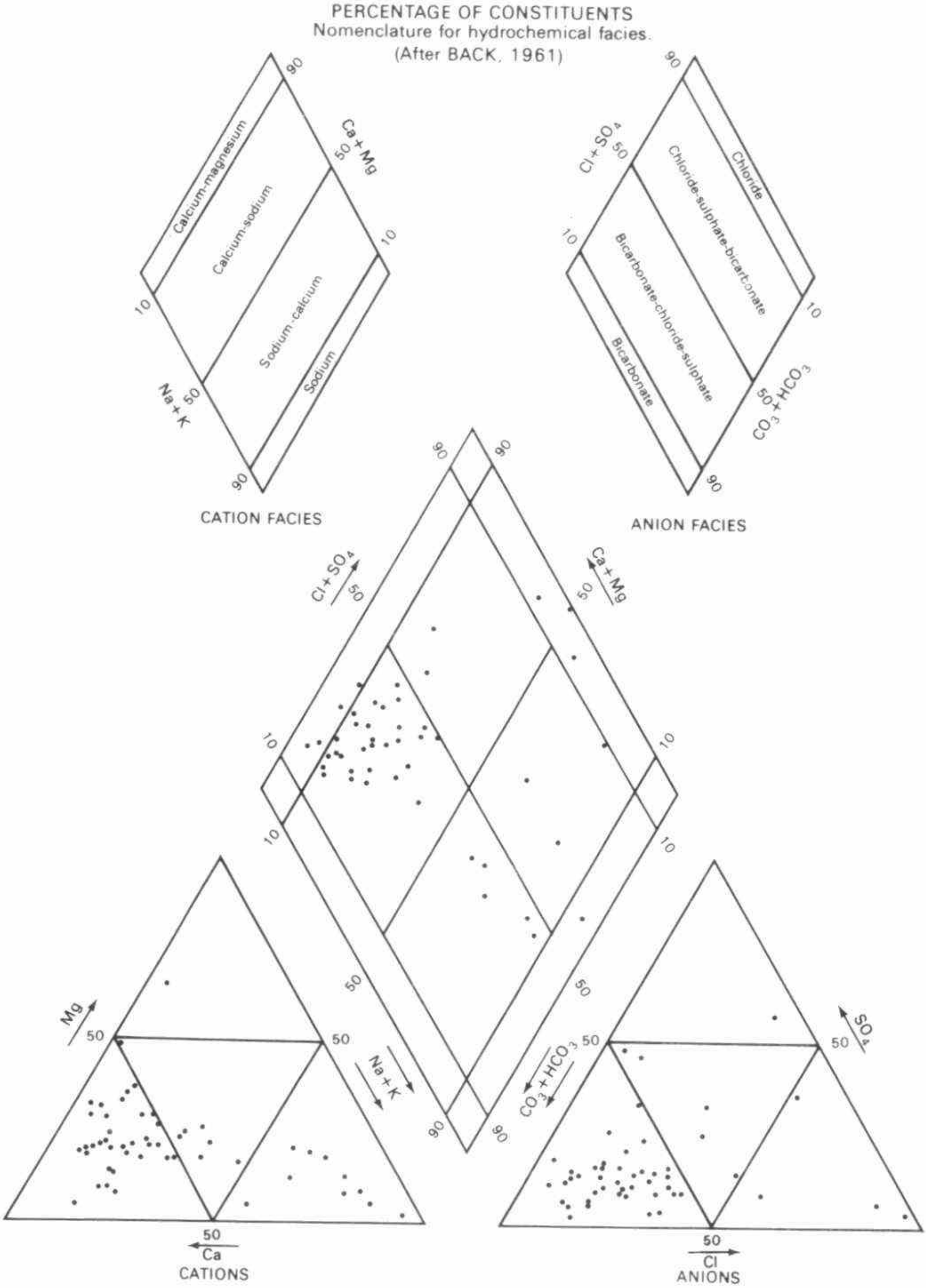


Figure 13. Piper trilinear plot of chemical analyses.

In order to identify and assess hydrochemical trends, the water samples are grouped by: (a) hydrochemical similarities; (b) the sampling area. The classification scheme proposed by Back (1961) and presented in Table 14, is used in this study to establish hydrochemical similarities. Water samples are classified into hydrochemical facies based on the percentage of predominant anions and cations in the water. This grouping is illustrated in the parallelograms which accompany Figure 13.

TABLE 14. CLASSIFICATION OF HYDROCHEMICAL FACIES (AFTER BACK, 1961)

	Constituent (present)			
	Ca+Mg	Na+K	HCO_3+CO_3	SO_4+Cl
Cation facies:				
Calcium-magnesium	90-100	0<10		
Calcium-sodium	50-90	10<50		
Sodium-calcium	10-50	50<90		
Sodium	0-10	90-100		
Anion facies:				
Bicarbonate			90-100	0<10
Bicarbonate-chloride-sulphate			50-90	10<50
Chloride-sulphate-bicarbonate			10-50	50<90
Chloride-sulphate			0-10	90-100

The majority of the ground-water samples fall into the calcium-magnesium and calcium-sodium cation facies and the bicarbonate-chloride-sulphate anion facies (Figure 13). These samples were collected from wells situated in different areas in the basin and completed to different depths. A total of 10 samples fall into the sodium and sodium-calcium cation facies, while 9 samples fall into the chloride-sulphate and chloride-sulphate-bicarbonate anion facies. These samples were generally collected from the deeper wells in the basin. This is a common phenomenon in this part of Ontario. Many of the deeper wells in the Belleville-Kingston-Cornwall area have been abandoned because high sodium chloride concentrations in the well waters have made the waters unpotable. Sulphate-type waters with sulphate concentrations in excess of bicarbonate concentrations occur in the deeper wells (80 feet+) in the Violet area. High sulphate concentrations occur in other parts of the basin; however, these waters are generally of the bicarbonate or chloride types.

In order to establish the distribution of the chemical constituents in the ground water in the basin and to illustrate changes in the proportion of ions from one area to the next, the sample analyses were grouped by the area in which they were collected. These groupings include samples collected near the head of the basin - the Harrowsmith - Hartington area, the center of the basin - the Violet area, and near the mouth of the basin - the Chambers area. As previously indicated ground-water flow is in a downslope direction from upland areas to the valleys and from the basin head and divide to the mouth. The results of the statistical treatment of the analyses listed in these groupings are presented in Table 15 along with ion ratios and the calculated levels of saturation.

The Harrowsmith - Hartington area covers the northern quarter of the basin, an area characterized by its strong topographic relief, which from the basin divide to the creek valley is in the order of 100-125 feet. The incised creek valley has well defined bedrock terraces which are for the most part obscured by sand and gravel deposits. Ground-water flow is from areas of high topographic relief downslope directly into the creek. Seepages are common along the valley walls. Water-well measurements taken in WC-1 (Figure 11) illustrate a vertical ground-water flow vector.

A total of 22 ground and 4 surface-water samples were collected in this area (Map 6, Table 13). Two of the ground-water samples were collected from observation well WC-1. This piezometer nest is established in the sand and gravel plug which acts as the upper basin divide. The waters from the two piezometers (25 and 63 feet in depth) have the lowest mineral content of any samples collected in the basin. The total dissolved solids content for the two samples are 370 and 110 mg/l, respectively. The rest of the ground-water samples were collected along Highway 38, in order to provide a hydrochemical section through the area. Figure 14 is a schematic cross-section illustrating the sample location, depth to water (based on well-log information) and the chloride and total dissolved solids (TDS) concentrations in the samples. No discernable trend could be established from this cross-section.

The samples collected in the Harrowsmith-Hartington area are typically of the calcium-bicarbonate type (Figure 13) with mean HCO_3/SO_4, HCO_3/Cl and SO_4/Cl values of 6.2, 4.0 and 0.9, respectively.

The Violet area is in the south-central portion of the basin. This area is a limestone plain with low relief and little overburden cover. The creek dissects the centre of the plain along a fault-controlled channel (Figure 3). Relief is in the order of 30 to 50 feet from the basin divide to the creek. Ground-water flow is in the direction of the creek.

A total of 17 ground-water and 2 surface water samples were collected in the Violet area (Map 6, Table 13). Detailed sampling was conducted along a traverse perpendicular to the creek. At this location the MOE has installed six observation wells and piezometer nests across the bedrock valley. Samples were collected from each of these installations and from domestic water wells along the section. The piezometric levels in the observation wells were measured prior to sampling. The measured piezometric levels and the chloride and TDS concentrations in the ground water are shown in Figure 15, a schematic cross-section through this area. Ground-water movement along this section is towards the stream with a downward gradient on the highs and an upward gradient in the valley. As is evident from the piezometer nests WC-3 and WC-6a, the chloride and TDS concentrations are higher for the deeper piezometers. The upward flow gradient and the high chloride and TDS concentrations in WC-3 at depth may indicate the presence of two distinct flow systems, a shallow local and an underlying regional system. Chloride and TDS concentrations are also higher in the shallow piezometers in the vicinity of the creek as opposed to the surrounding uplands. This would in part demonstrate an increase in the mineralization of the ground water as it moves towards the stream and possibly a mixing phenomenon of the shallow and deeper waters.

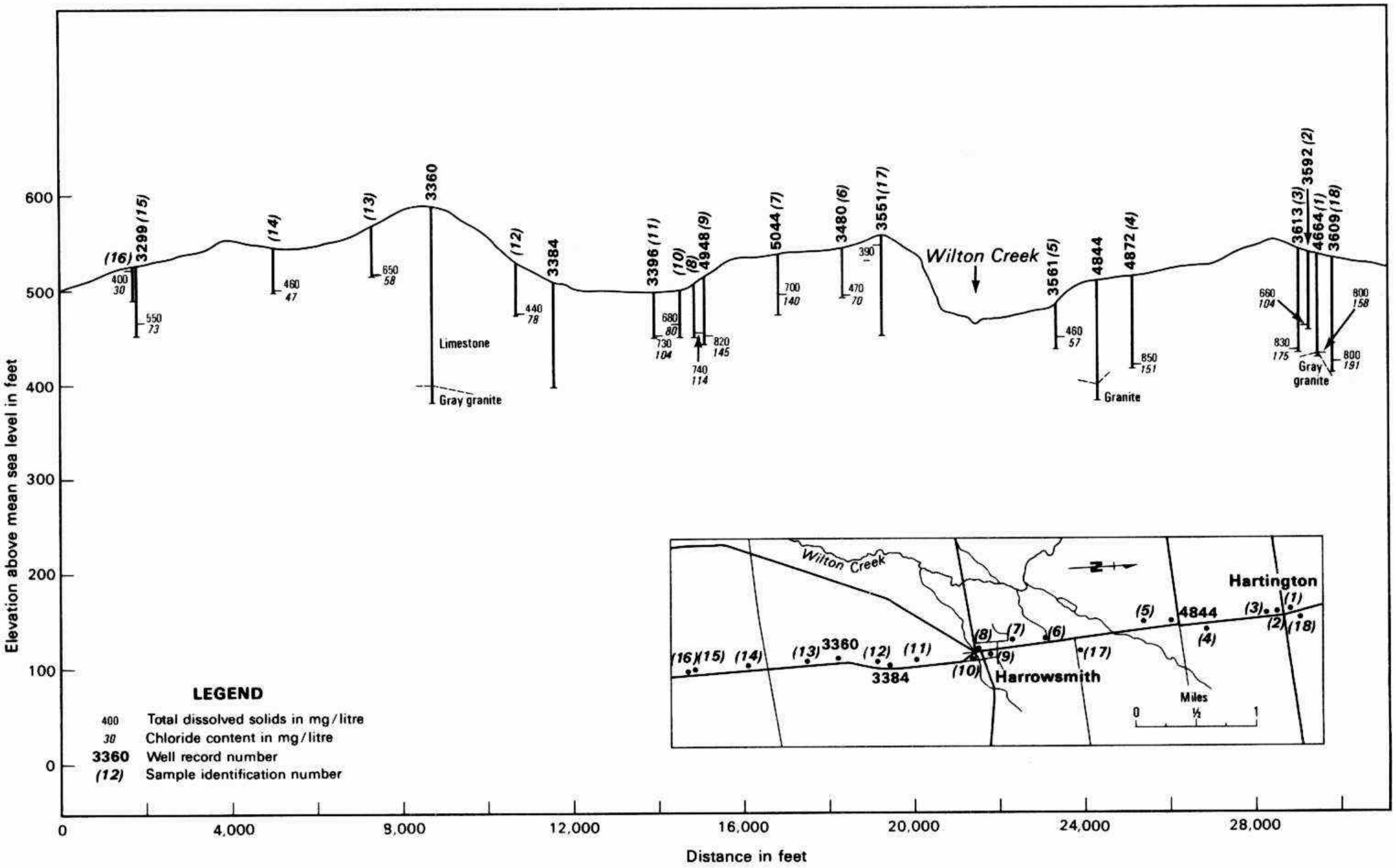


Figure 14. Cross-section along Highway 38 illustrating the chloride and total dissolved solids content in the ground water.

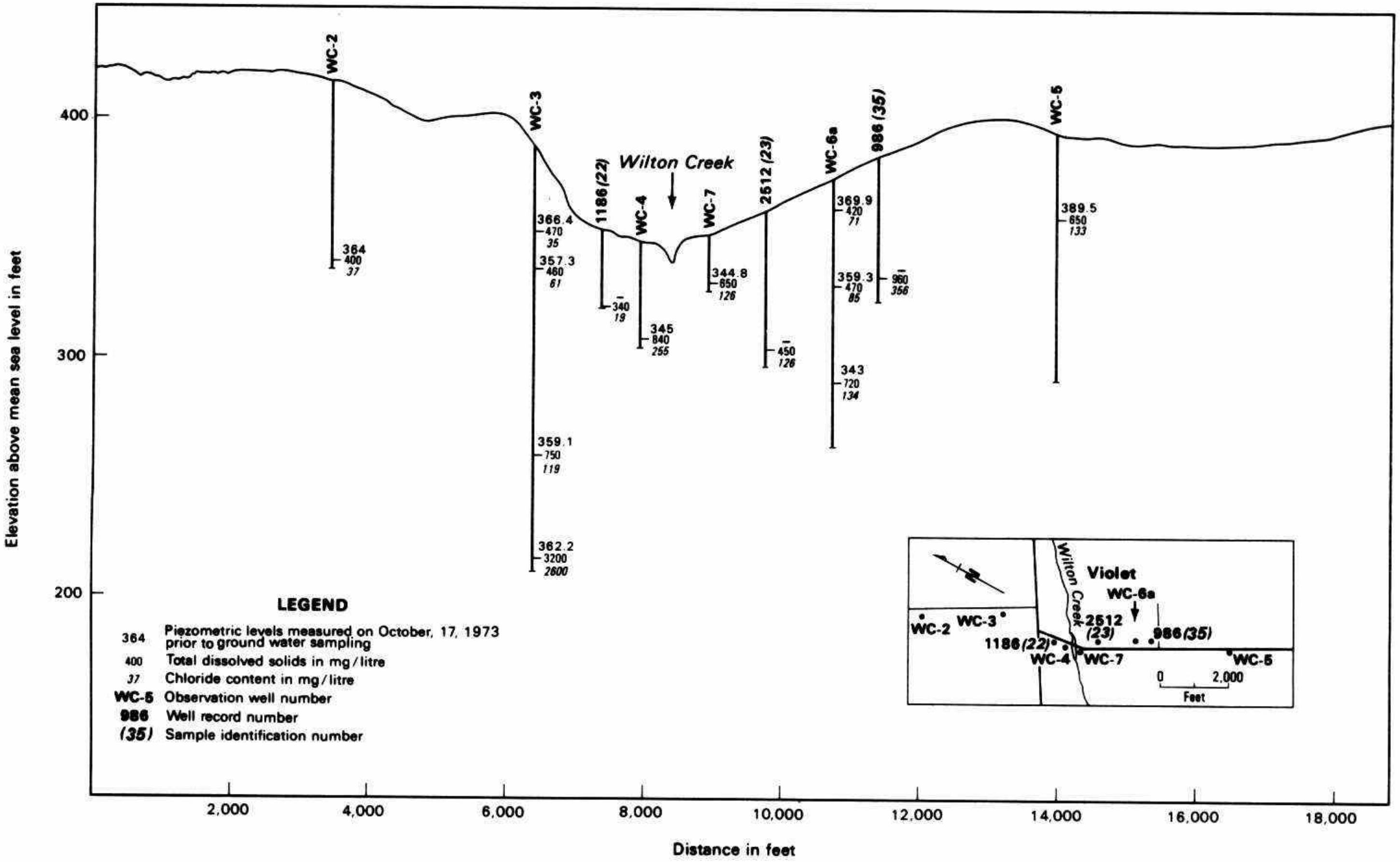


Figure 15. A north-south cross-section through the observation wells near Violet illustrating the piezometric levels and the chloride and total dissolved solids content in the ground water.

For purposes of comparison, the water sample analyses for the Violet area are separated into two groups on the basis of hydrochemical simlarities. Group A samples are classified as being of the calcium-bicarbonate type. These samples were collected from wells ranging in depth from 13 to 103 feet. The hydrochemistry of these samples is similar to that of the samples collected in the Harrowsmith-Hartington. The mean HCO_3/SO_4, HCO_3/Cl and SO_4/Cl values are 5.5, 3.4 and 0.65, respectively.

Group B samples are classified as being of the sodium-sulphate-chloride type. These samples are typically more mineralized than those of either Group A or of the Harrowsmith - Hartington area. Three of the samples WC-3a, WC-3b and WC-6c have HCO_3/SO_4 values (0.2, 0.3 and 0.1, respectively) which are well below those from other areas. Samples WC-3a, and DW-29 have chloride contents (2600 and 636 mg/l) which are above those of the Harrowsmith - Hartington area and the Group A samples. The Group B samples range in depth from 85 to 178 feet. The mean HCO_3/SO_4, HCO_3/Cl and SO_4/Cl values are 1.2, 0.3 and 0.6, respectively.

The Chambers area is in the southern reaches of the basin. This area is a near flat plain with relief in the order of 25 feet. Overburden deposits such as drumlins, have modified the local topography. Ground-water flow in this area has a downward and lateral vector near the basin divide and an upward vector in the vicinity of the creek and creek mouth. This is borne out in observation well WC-8 where there is a strong upward vector to the ground-water flow (Figure 12).

A total of 10 ground and 4 surface-water samples were collected in this area (Map 6, Table 13). The ground-water samples are divided into two groups on the basis of their hydrochemical character. Group C samples were collected from shallow (19-60 ft.) wells in this area. These wells are typically of the calcium-bicarbonate type. The mean HCO_3/SO_3, HCO_3/Cl and SO_4/Cl values for the samples which fall into this category are 14.8, 8.3 and 1.2, respectively.

Group D, represented by two samples, is characterized by waters of the sodium - bicarbonate - chloride type. Two samples were collected from observation well WC-8, one from the deep (178 feet) and one from the shallow (29 feet) piezometers. Both samples have a high pH measurement and similar Ca (330 and 320 mg/l) and Mg (75 and 59 mg/l) contents. The shallow sample has a distinctive calcium-bicarbonate character, whereas the deep samples is of the sodium-chloride type. The mean HCO_3/SO_4, HCO_3/Cl and SO_4/Cl values for WC-8f and DW-21 are 9.8, 0.9 and 0.1, respectively.

The following conclusions can be drawn from the distribution of the chemical constituents in the ground waters of the basin:

1. The chemical composition of the ground water changes as the water moves through the basin. This change is apparent from the grouping of the samples by area. The total dissolved solids concentration and the proportion of chloride and sulphate concentrations with respect to the bicarbonate concentration increase in the direction of ground-water movement.
2. The chemical concentration (as represented by the TDS concentration) in the ground waters is greater for deep wells in the Violet and Chambers area then shallow wells.

3. The chemical concentration (based on wells in the Violet area) is greater in ground-water samples collected from wells in the vicinity of the creek then in samples from wells in the adjacent upland areas. Ground-water flow is towards the creek.
4. The chemical composition of the ground-water samples collected in the upper reaches of the basin and most of the shallow wells in the other areas have a similar calcium-bicarbonate character.

The surface water samples collected in the basin are of the calcium - bicarbonate type. There is a general increase in the total dissolved solids, sodium and chloride concentrations in the water from the north to south. The other major constituents in the water are constant.

Suitability of Ground and Surface Waters for Use

The chemical quality of the ground and surface waters of an area is an important consideration in evaluating the suitability of these waters for specific uses. These waters should not contain constituents in concentrations which may render them harmful to the use to which they may be put. The Ontario Ministry of the Environment has established a series of water quality criteria for the Province based on the major water use categories. These criteria are presented and discussed in the MOE booklet entitled "Guidelines and Criteria for Water Quality Management in Ontario" (1974). The published criteria are listed under permissible and desirable concentrations. Waters which exceed the permissible concentration criteria should not be used for supply purposes. Good quality waters are those which meet the desirable concentration criteria. The permissible and desirable concentration criteria for some of the major chemical constituents for public water supples are presented below:

Chemical Constituents	Permissible Criteria (in mg/l)	Desirable Criteria (in mg/l)
Sulphate	250	<50
Total Dissolved Solids	500	<200
Chloride	250	<25
Chloride Hardness	Acceptable levels will vary with local hydrogeologic conditions and consumer acceptance.	
Nitrate as N	10	virtually absent
Iron (filterable)	0.3	virtually absent
pH range	6.0-8.5 units	least amount of interference with treatment process.
Pollution Indicator Organisms	Coliform and other pollution organisms should be virtually absent from all supplies.	

The ground and surface waters in the basin are typically hard (30-1850 mg/l for ground water, 150-322 mg/l for surface water). Acceptable levels of hardness vary with the use to which the water is put. Of the total of 49 ground-water analyses presented in this study, 28 (57%) exceed the permissible criteria standards for TDS, 6 (12%) for chloride and 1 (2%) for sulphate. The surface water samples meet the permissible criteria standards.

The microbiological content of the water supply should be established prior to use by submitting a sample of the water to the local Health Unit for examination. Nuisance organisms should be virtually absent from water supples. Where they occur it will be necessary to disinfect the water supply.

The suitability of the water for irrigation should be established through the local agricultural representative. The relative tolerance of crop plants to different chemical constituents in the water varies considerable and should be established prior to the initiation of irrigation.

SUMMARY

This report presents the findings of a study conducted on the geology and ground-water resources of the Wilton Creek drainage basin. The Wilton Creek drainage basin in one of the seven basins studied by the Ontario Ministry of the Environment, as its contribution to the International Hydrological Decade (IHD) Representative Basin Program. Studies conducted on this basin consisted of the collection and interpretation of geological and ground and surface-water data through field surveys, the installation and periodic measurement of eight observation-well installations and two streamflow recording stations, and surface and ground-water sampling.

The drainage basin lies within the Napanee Plain physiographic region, a flat plain of limestone which dips gently to the southwest resulting in a series of shallow erosional scarps. Surface relief is provided by drainage and glacial erosion. The overburden is thin and discontinuous for the most part; however, local thicknesses in the order of 90 feet have been recorded in the southern reaches of the basin.

The climate is influenced by the moderating effects of Lake Ontario. The mean annual temperature at Hartington for the interval 1968 to 1973 is 43.3°F. The mean annual precipitation for that interval is 36.33 inches at Hartington and 36.44 inches at Violet.

The bedrock is comprised of Precambrian metamorphic and igneous rocks overlain non-conformably by Cambrian and Ordovician sedimentary rocks (Map 1). The sedimentary succession consists of conglomerates, sandstones, shales and carbonates of the Basal and Simcoe groups. The Basal Group includes the Potsdam and Shadow Lake formations. The Simcoe Group includes four rock units, the Lindsay, Verulam, Bobcaygeon and Gull River formations. The uppermost unit, the Lindsay Formation, is not present in the basin area.

The Pleistocene overburden includes glacial tills, glaciofluvial sands and gravels and stratified glaciolacustrine silts and clays (Map 2). Deposition appears to have occurred along an oscillating ice front. The lack of Lake Iroquois beach and near-shore deposits suggest that the ice margin may have been floated clear of the land surface by the buoyant action of Lake Iroquois waters. A single lacustrine shore feature, a gravel bar south of Morven, has been related to a brief transitory post-Lake Iroquois stage, Lake Belleville.

Ground water is the major source of domestic water supply. The carbonate bedrock of the Simcoe Group constitutes the principal aquifer. Ground-water availability and quantity is related to the number of interstitial openings such as fractures in the aquifer and their degree of interconnection. The density of openings varies both with location and depth in the aquifer.

The calculated coefficients of transmissibility range from 90-3900 Igpd/ft. A single permeability value is in the order of 100 Igpd/ft^2 and the coefficient of storage is estimated to be 4×10^{-4}. The mean coefficient of transmissibility as estimated from specific-capacity values is 2,300 Igpd/ft.

On the basis of productivity-frequency graphs prepared from adjusted specific-capacity values and the statistical treatment of these values, significant relationships exist between the well productivity and 1) the depth of penetration by the well, 2) the position of the well relative to topography and 3) the bedrock units encountered. Shallow wells and wells finished in valleys are more productive than deep wells and wells finished in upland areas.

The till and lacustrine deposits act as a low permeable mantle, creating semi-confined aquifer conditions. The sand and gravel deposits constitute locally favourable aquifers; however, their thickness and areal extent are too small to yield anything but small domestic water supplies. The mean coefficient of transmissibility of the overburden, as estimated from specific-capacity data, is 1400 Igpd/ft. The mean permeability as estimated from grain-size distribution is in the order of 860 Igpd/ft^2.

Ground-water flow in the basin is strongly influenced by the local topographic relief. Ground water moves from upland areas to valleys and in a more general manner from the head of the basin to the mouth. The ground-water level fluctuates seasonally with the greatest rise occurring during the spring-melt period. Water-level fluctuations as measured in observations wells vary from 0.7 to 34.0 feet over the basin, depending on well location and depth. There are no noticable long-term changes in ground-water levels over the period 1967 to 1973.

A simplified hydrologic budget was estimated for the water-year interval 1967-68 to 1973-74 using the following equation:

$$P = R_g + R_s + ET$$

where:

P = precipitation
R_g = ground water runoff or baseflow
R_s = surface runoff
ET = evapotranspiration

Precipitation for the seven-year period, as averaged for Hartington and Morven, is 37.04 inches/year. The mean total streamflow runoff for the same period, as measured at hydrometric station 3MH-004, averaged 16.40 inches/year, while the ground-water runoff component (estimated from the monthly minimum streamflow) averaged 3.97 inches/year (24.2% of total streamflow). The potential evapotranspiration as estimated by the Munson-Index method is 22.68 inches/year. The evapotranspiration loss calculated by the water-balance equation is 20.64 inchs/year. The difference (2.04 inches/year) between the potential evapotranspiration and that calculated by the water-balance equation represents the cumulated errors inherent in the estimation of the components of the budget and net changes in basin storage and basin underflow, which have not been measured directly.

A total of 38 ground-water and 15 surface water samples were collected at different locations in the basin to establish the chemical composition of the waters. The ground-water samples were arbitrarily divided into three groups based on location and hydrochemical similarities. The following trends became apparent by this grouping:

1. The chemical composition of the ground water changes as the waters move through the basin; TDS content increases in a downgradient direction.
2. The TDS concentration is greater in water samples collected from deep wells in the Violet and Chambers area than shallow wells.
3. Ground water in the vicinity of the creek has a greater mineral content then that in the adjacent upland areas.
4. Ground water collected in the upper reaches of the basin and in most shallow wells, is of similar composition, being of the calcium-bicarbonate type.

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APPENDIX A

GUIDE TO THE BEDROCK
AND OVERBURDEN GEOLOGY
OF THE
WILTON CREEK DRAINAGE BASIN

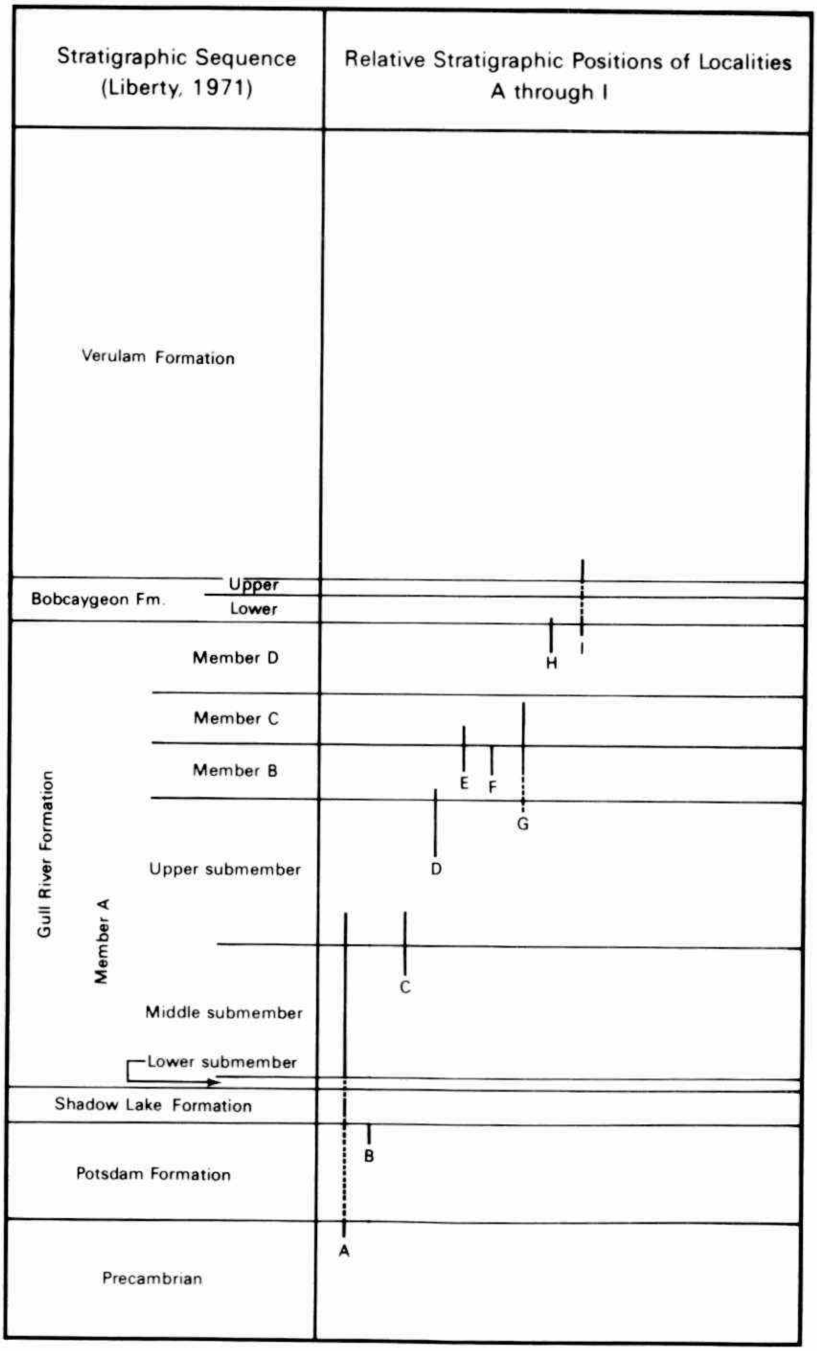
(compiled during 1973)

Table 16. Stratigraphic units present at site localities A to I.

Figure 16. Location map for sites referred to in the Guide.

Figure 17. General diagram of the landfill site near Violet with locations of the sections cited in the Guide.

TABLE 16. STRATIGRAPHIC UNITS PRESENT AT SITE LOCALITIES A TO I



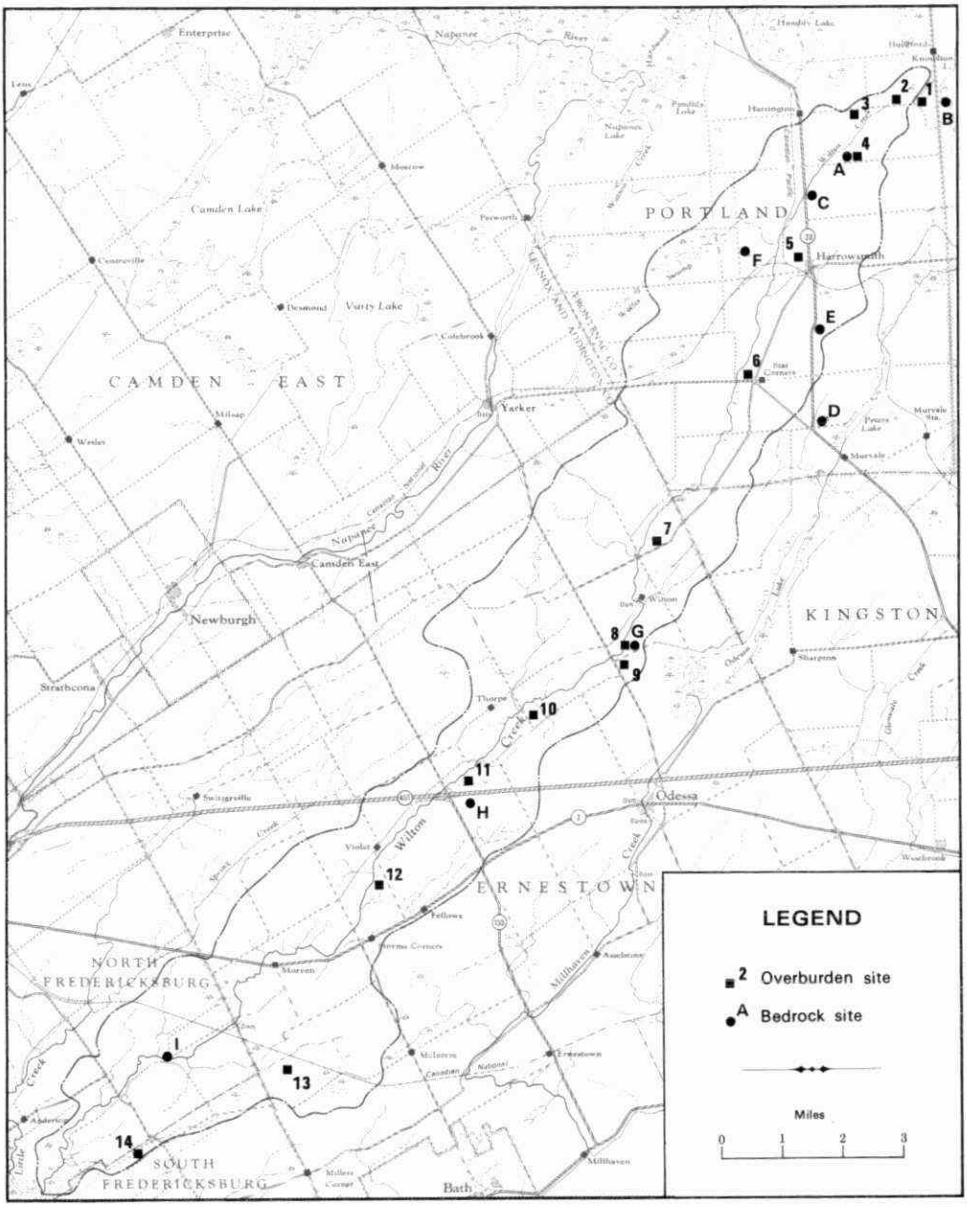


Figure 16. Location map for sites referred to in the Guide.

Guide to the bedrock geology of the Wilton Creek drainage basin. Stratigraphic distribution is presented in Table 16 and site locations in Figure 16.

A. PRECAMBRIAN

- The Precambrian is exposed in a sand and gravel pit in the Wilton Creek valley, northeast of Harrowsmith.
- The Precambrian at this locality is composed of granite gneiss in the form of an inlier with an estimated relief of about 75 feet (determined from adjacent water-well logs).
- Overlying the Precambrian unconformably, are the Shadow Lake and Gull River formations (Text Photo 1a).

Sequence Exposed

Gull River	Member A	upper submember middle submember
Shadow Lake		
Precambrian		

- The upper submember of Member A may be observed higher up on the valley wall east of this location, at approximately 550 feet. The lower 20 feet of the Gull River Formation is not exposed at this location.
- The absence of the Potsdam Formation is explained by the onlapping of the Paleozoic sequence over the Precambrian highs. The Potsdam Formation although occurring near the base of the inlier, thins out higher on the flanks (see Text Figure 2).

B. POTSDAM FORMATION

- Although the Potsdam Formation does not outcrop in the basin, it is inferred to be present from water-well logs.
- The Potsdam Formation examined to the northeast of the basin on the shore of Knowlton Lake, consists of a fine to medium - grained red quartz sandstone. The quartz grains are well-rounded. Hematite and calcite make up the cementing matrix.
- Numerous exposures of the Potsdam Formation occur north of Kingston (Text photos 2 and 3).

C. GULL RIVER FORMATION (MIDDLE AND UPPER SUB-MEMBERS OF MEMBER A)

- These submembers are exposed at a roadcut about 1/2 mile north of Harrowsmith on Highway 38.
- The contact between the submembers is represented by a 2-foot thick layer of green-black shale.
- The elevation for the contact is approximately 500 feet.
- There appears to be little lithological variation between the two submembers, although the middle submember is thicker.
- Beds of the middle submember, about 10-15 feet below the contact, are fossilferous and can be used as marker beds locally.

D. GULL RIVER FORMATION (CONTACT BETWEEN MEMBERS A AND B)

- The contact between the upper submember of Member A with Member B is exposed about 3/4 mile north of Murvale on Highway 38. The contact is marked by colour changes in the limestone.
- The lithology is repetitive with the exception of a decreasing calcite vug content above the contact.

E. GULL RIVER FORMATION (MEMBER B)

- The member is partially exposed 3/4 mile south of Harrowsmith on Highway 38.
- It consists of alternate beds of massive limestone and thin beds of friable and argillaceous limestone which is fossiliferous and contains numerous calcite vugs.
- The exposure appears to be the upper submember.

F. GULL RIVER FORMATION (MEMBER B)

- Member B is partially exposed west of Harrowsmith in a series of outcropping erosional scarps made up of hard beds, while the soft beds are not exposed.

G. GULL RIVER FORMATION (CONTACT BETWEEN MEMBERS B AND C)

- This bedrock exposure occurs as a terraced surface in a sand and gravel pit southeast of Wilton.
- The contact between Members B and C is exposed on the bedrock terrace at approximately the 450-feet contour.
- Member C is more "arkosic" and is highly fossiliferous.
- Stromatolites are exposed near the abandoned office building of the sand and gravel pit.

H. GULL RIVER FORMATION - BOBCAYGEON FORMATION CONTACT

- This contact is visible on Highway 401 in a road-cut east of the Highway 401 and Highway 133 intersection.
- The contact is distinctive between the more massive Gull River (Member D) and the friable argillaceous Bobcaygeon limestone (Text Photo 11).

I. GULL RIVER - BOBCAYGEON - VERULAM FORMATION

- These formations are all exposed in the vicinity of Chambers.
- The Gull River Formation, Member D, is visible in the streambed as is the Bobcaygeon, while the Verulam Formation is exposed further south in two abandoned quarries.
- Text Photo 12 shows the Verulam Formation.

GUIDE TO OVERBURDEN GEOLOGY OF THE WILTON CREEK DRAINAGE BASIN

1. Sand, Gravel and Till "Plug".

- At this location, a sand, gravel and till plug fills the Wilton Creek Valley and acts as a drainage divide between the Creek and Knowlton Lake.
- The plug appears to act as the source area for Wilton Creek.
- The following section is exposed in a small pit on the Knowlton Lake side of the plug:

Thickness	
2-10 Feet:	Sandy till with few stones, very similar to the underlying glaciofluvial sands (Kame deposit ?).
20 + Feet:	Medium-grained sand, good sorting.

2. Sand and Gravel Pit (1-1/2 miles east of Hartington).

- At this locality sand and gravel fills the base of the valley and occurs along its terraced bedrock sides.
- This sand and gravel appears to be a continuation of the plug down the creek valley.
- The exposed section is presented below:

Thickness	
2 Feet:	Sandy till with few stones, local thickness to 5 feet.
15 Feet:	Medium sand, well sorted.
5 Feet:	Coarse sand and gravel, layer of well-rounded boulders which is assumed to be ice contact in origin.

3. Kame Terrace Sand and Gravel and a Limestone Quarry (1 mile east of Hartington)

- The limestone quarry is in the middle submember of Member A of the Gull River Formation.
- The sand and gravel along the side of the valley is deposited on bedrock terraces.
- The exposed section is presented below:

Thickness	
2 Feet:	Sandy till with few boulders.
3-5 Feet:	Medium sand, stratified and well sorted.
10 Feet:	Coarse sand and gravel, poor to fair sorting.

- There is water seepage from the base of the coarse sand.

4. Sand and Gravel Pit (northeast of Harrowsmith)

- Kame terrace deposit which has been largely exploited.
- No undisturbed sections present.
- Sand and gravel can be found on a series of terraces up to an elevation of 575 feet.

5. Active Sand and Gravel Pit (near Harrowsmith)

- Sand and gravel deposited along the side of the creek valley in the form of a kame terrace deposit.
- The bedrock is exposed in several areas. There are numerous fractures and glacial striations.
- Fracture and striae trends are presented below:

Fracture Trends:

017°. 357°, 347°, 334°, 012°, 020°, 014°, 012°

Striations:

234°, 237°, 242°, 240°

- The exposed section at this locality is as follows:

Thickness	
2-5 Feet:	Sandy till with few stones, strongly weathered.
10-20 Feet:	Medium sand, cross bedded with forsets dipping to the southeast, sand rests on bedrock.

- Sand thins out towards the east and the south, local pockets of coarser sand and gravel.
- Seepage at base of the sand.

6. Abandoned Sand and Gravel Pit (two miles southwest of Harrowsmith on west side of Highway 4-A)

- Kame terrace deposit along the side of the valley.
- Exposed section is presented below:

Thickness	
25 Feet:	Sandy till with few stones.
<50 Feet:	Sand and gravel has been removed; thickness is assumed.

7. Active Sand Pit (north of Wilton on Highway 4-A)

- This appears to be a continuation of the sand terraces found both to the southwest and northeast of this deposit.
- Deposit is exposed on both sides of the road, (with sand resting on the bedrock terraces).
- The section on the south side of the road is presented below:

Thickness	
3 Feet:	Sandy till with few boulders, soil profile developed.
1 Foot:	Stoney till, dense.
10 Feet +:	Fine to medium sand, stratified and well sorted.

- Ground-water seepage is evident at the base of the sand.
- Fracture and striae trends are presented below:

Fracture Trends:

347°, 357°, 358°, 357°, 358°

Striations:

222°, 227°

- The section on the north side of the road is presented below:

Thickness	
1 Foot:	Till (upper surface has been stripped so thickness is not measureable).
15-20 Feet:	Medium-grained sands, foreset beds dip to the southwest.

8. Sand and Gravel Pit (south of Wilton on east side of creek)

- Most of the sand and gravel has been removed from this terrace deposit.
- No evidence of till.
- Water table is near the base of the sand.
- The section is presented below:

Thickness	
4 Feet:	Silty clay layer, strongly weathered.
1/2 Foot:	Massive dense clay.
10 Feet +:	Sand and silt, medium-grained sand is well stratified, coarser-grained sand underlies the medium-grained sand locally.

9. Sand and Gravel Pit (southwest of (8) about 1/2 mile)

- The exposed section is presented below:

Thickness:	
4-5 Feet:	Sandy-silty till, well developed soil horizon.
25-35 Feet:	Medium, cross-bedded sand, foreset beds dip to southwest.
10-15 Feet:	Coarse sand and gravel of which the lower 5-8 Feet are saturated.

- The pit must be dewatered continuously during the spring and early summer (Photo 24).

10. Large Drumlin (southeast of Thorpe)

- Drumlin has a stratified sand and gravel core covered by a 2 to 5-foot till layer.
- Sand and gravel pit developed on the northeast end of the drumlin with about 20 feet of unsorted sand and gravel exposed (Photo 16).

11. Sand and Gravel Pit (northeast of the intersection of highways 133 and 401).

- Well developed bedrock terraces upon which interbedded clay, silt, sand and gravel have been deposited.
- Sand is stratified, foreset beds dip to southwest.
- Measured sections are presented below:

Southeast End Of Pit:

Thickness	
4 Feet:	Sandy, silty till, few boulders, weathered profile.
	———gradational contact.———
4 Feet:	Medium, well-sorted sand.
	———Sharp contact.———
1 Inch:	Dense clay.
9 Inches:	Interbedded sand and reddish brown silty-sand till.
1 Foot:	Medium-grained sand.
2 Feet:	Silt and clay.
2-1/2 Feet:	Medium-grained sand, becomes increasingly siltier towards the base.
	———Scalloped contact.———
1 Foot:	Silty till with clay layer (1 inch).
4 Feet:	Medium sand and gravel near base.
5 Inches:	Dense red-brown silty till (text Photo 14) clay, sand, till, red clay, till, sand.
9 Inches:	Clay and sand.
4 Feet:	Medium sand.
1 Inch:	Gravel.
1 Foot:	Medium and coarse sand.

- Sand lies on a limestone terrace.
- Central portion of the pit may contain another 10+ feet of sand on a lower terrace; however, it was flooded during field work.

Northeast End of the Pit:

Thickness	
3 Feet:	Silt and sand (possible a strongly weathered till).
3 Feet:	Medium sand.
8 Feet:	Stoney clay till interbedded with sands above a bedrock terrace.

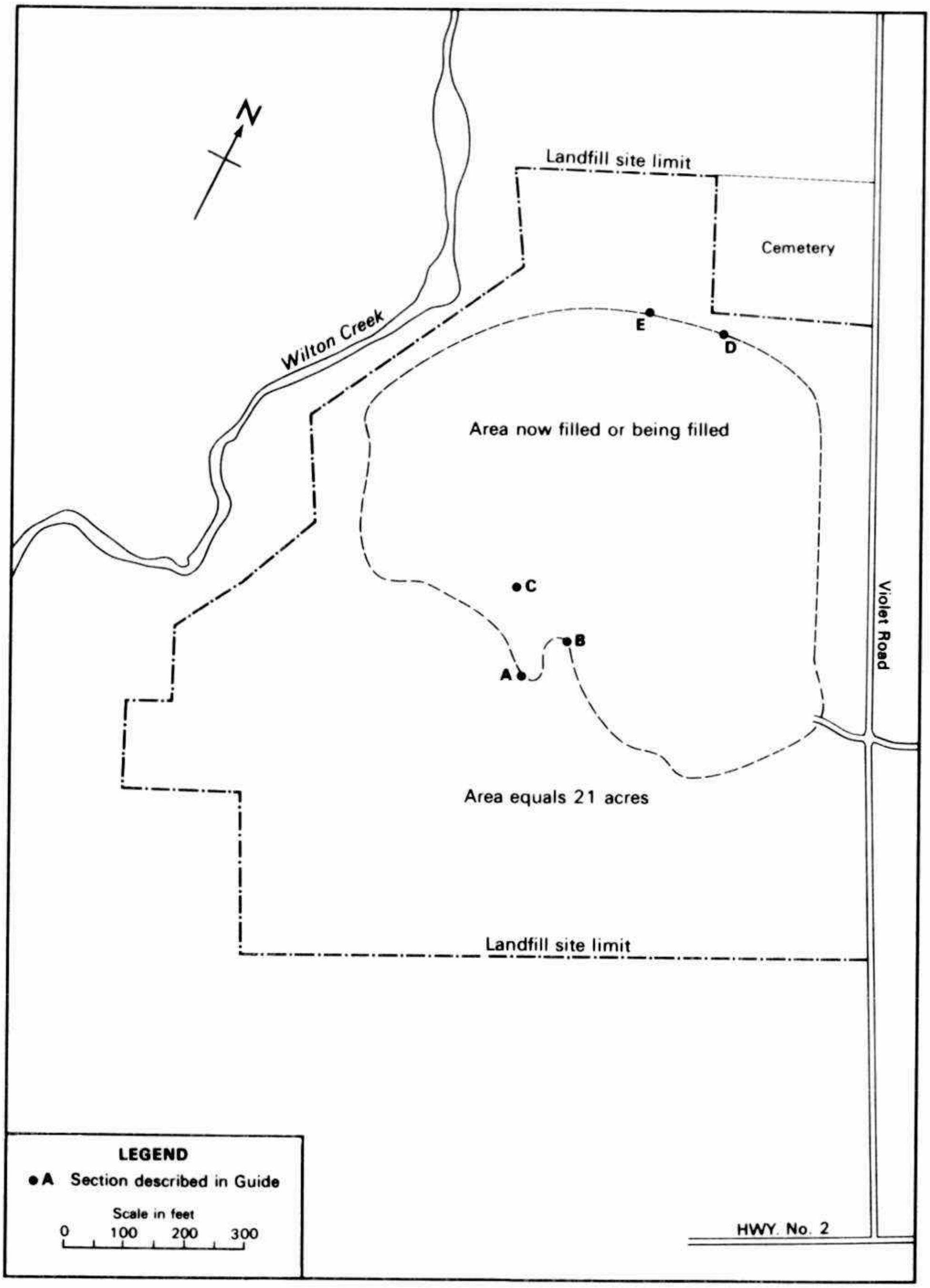


Figure 17. General diagram of the landfill site near Violet with locations of the sections cited in the Guide.

- There is considerable seepage at the base of the sand.
- Fracture trends and striae measurements are given below:

Fracture Trends:

030°, 040°, 300°, 042°, 300°, 042°

Striations:

236°, 234°, 238°

12. Sanitary Landfill Site (near Violet)

- Originally a sand and gravel pit, presently being backfilled with solid waste.

- There is ground-water seepage from the base of the sand near the bedrock contact.

Fracture Trends:

320°, 328°, 022°, 292°, 299°, 289°, 004°, 354°, 339°, 344°, 277°, 277°, 287°

Striations:

236°, 234°

- Various measured sections A - F are presented as follows:

Section A.

Thickness	
3 Feet:	Weathered silt - clay layer with soil profile.
2 Feet:	Cross-bedded silt and clay - reworked clay fragments at the base of this layer.
3 Inches:	Till - dense red silty-clay till, abundant stones.
6 Inches:	Medium sand - sand grades into till.
8 Inches:	Till - stoney, sand.
18 Feet:	Medium sand, good sorting, base is not exposed.

Section B.

Thickness		
3 Feet:	Weathered silty clay, soil profile.	
6 Inches:	Clay till, moderate stone content.	
3 Inches:	Stratified sand and silt layer.	
6 Inches:	Compact silty till.	
1 Foot:	Coarse sand.	
2 Feet:	Gravel	foreset beds dip the southwest
18 Feet:	Medium and fine sand.	

Section C.

- Up to 20 feet of coarse sand.
- Location is on a lower bedrock terrace, the base of which is flooded.
- Sand and gravel can be traced along bedrock terrace southwest to County Road.

Section D.

Thickness	
5 Feet:	Silty clay, soil profile.
2 Feet:	Brown clay, evenly-bedded, graded bedding.
6 Inches:	Silty clay.
9 Inches:	Stoney sandy till.
1 Inch:	Dense, plastic clay, red-brown colour.
7 Inches:	Stoney sandy till.
2 Inches:	Gravel layer.
20 Feet:	Medium, cross-bedded sand - undulating (scalloped) surface suggest overriding.

Section E

Thickness	
4 Feet:	Silty clay, evenly-bedded, soil profile.
6 Inches:	Stoney till, dense, some clay balls.
5 Feet +:	Clay-silt varves, good bedding.

- Base is buried. It is assumed that till underlies the clay, as inferred from adjacent area.

Varves slightly west of Section E appear to represent a local ponding in the immediate area.

13. "Beach Remnant" (north side of drumlin near the borders of the townships of North Fredericksburg, South Fredericksburg and Ernestown).

- This site, described by Mirynech (1967), is a wave-modified Quinte Bay drumlin.
- This "beach remnant" suggests a brief water stand, the Belleville Stage (Mirynech, 1962).
- A wave-deposited gravel bar present on the northeast flank of the drumlin extends for about 1 mile.
- The deposit has been exploited for the gravel.

14. Qunite Bay Drumlin (on Highway 8 near the lower edge of the basin).

- Typical long, low-lying drumlin about 30-40 feet high.

APPENDIX B

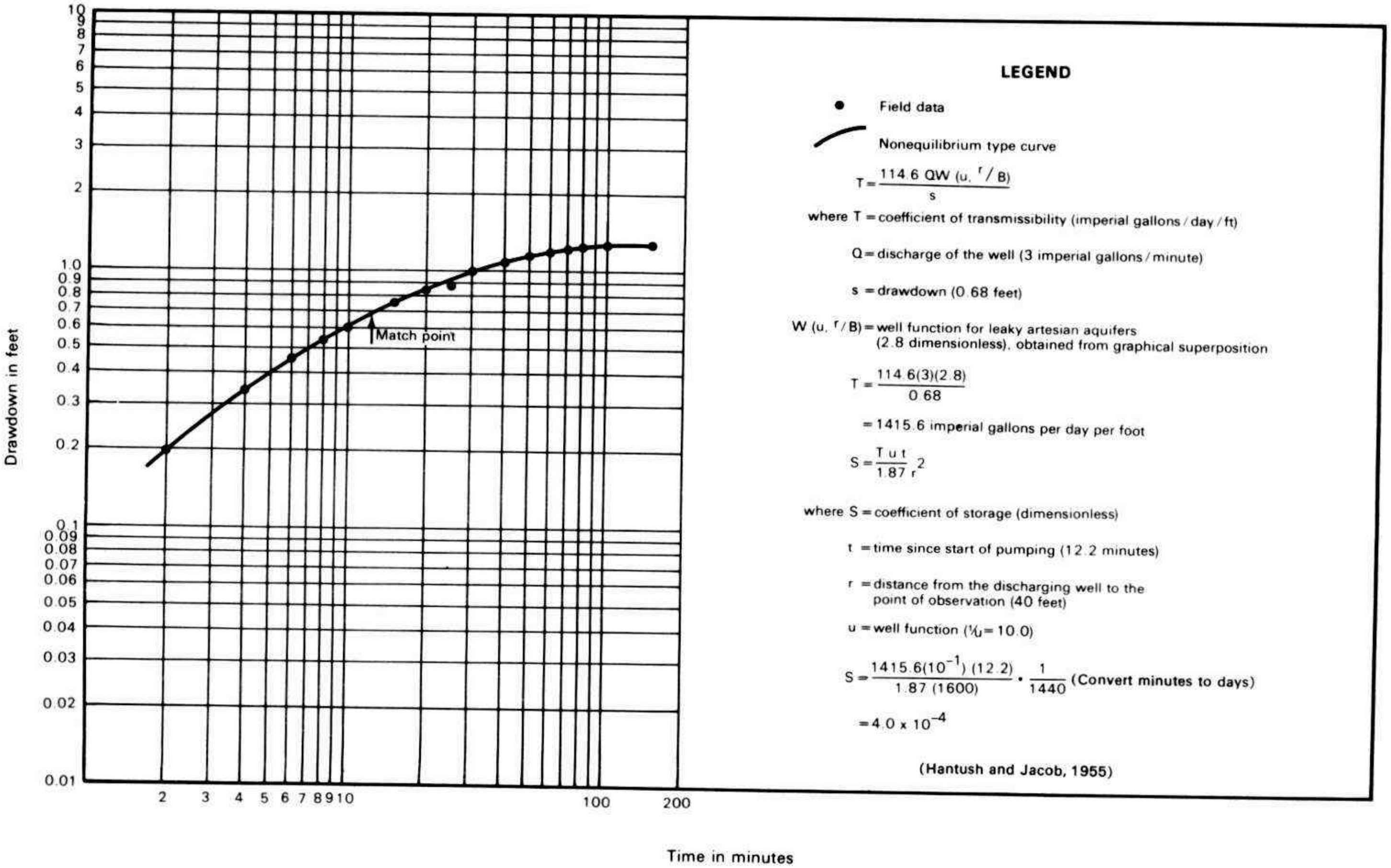
PUMPING TEST DATA

Figure 18. Time-drawdown curve of an observation well near WC-7.

Figure 19. Time-drawdown data for pumped well WC-7.

Figure 20. Time-drawdown data for pumped well WC-4.

Figure 21. Time-drawdown data for pumped well at service centre E-5.



LEGEND

● Field data

Nonequilibrium type curve

$$T = \frac{114.6\ QW\ (u,\ ^{r}/B)}{s}$$

where T = coefficient of transmissibility (imperial gallons / day / ft)

Q = discharge of the well (3 imperial gallons / minute)

s = drawdown (0.68 feet)

W (u, ^{r}/ B) = well function for leaky artesian aquifers (2.8 dimensionless), obtained from graphical superposition

$$T = \frac{114.6(3)(2.8)}{0.68}$$

= 1415.6 imperial gallons per day per foot

$$S = \frac{T\ u\ t}{1.87\ r^{2}}$$

where S = coefficient of storage (dimensionless)

t = time since start of pumping (12.2 minutes)

r = distance from the discharging well to the point of observation (40 feet)

u = well function ($^1/_u$ = 10.0)

$$S = \frac{1415.6(10^{-1})\ (12.2)}{1.87\ (1600)} \cdot \frac{1}{1440}\ \text{(Convert minutes to days)}$$

$= 4.0 \times 10^{-4}$

(Hantush and Jacob, 1955)

Figure 18. Time-drawdown curve of an observation well near WC-7

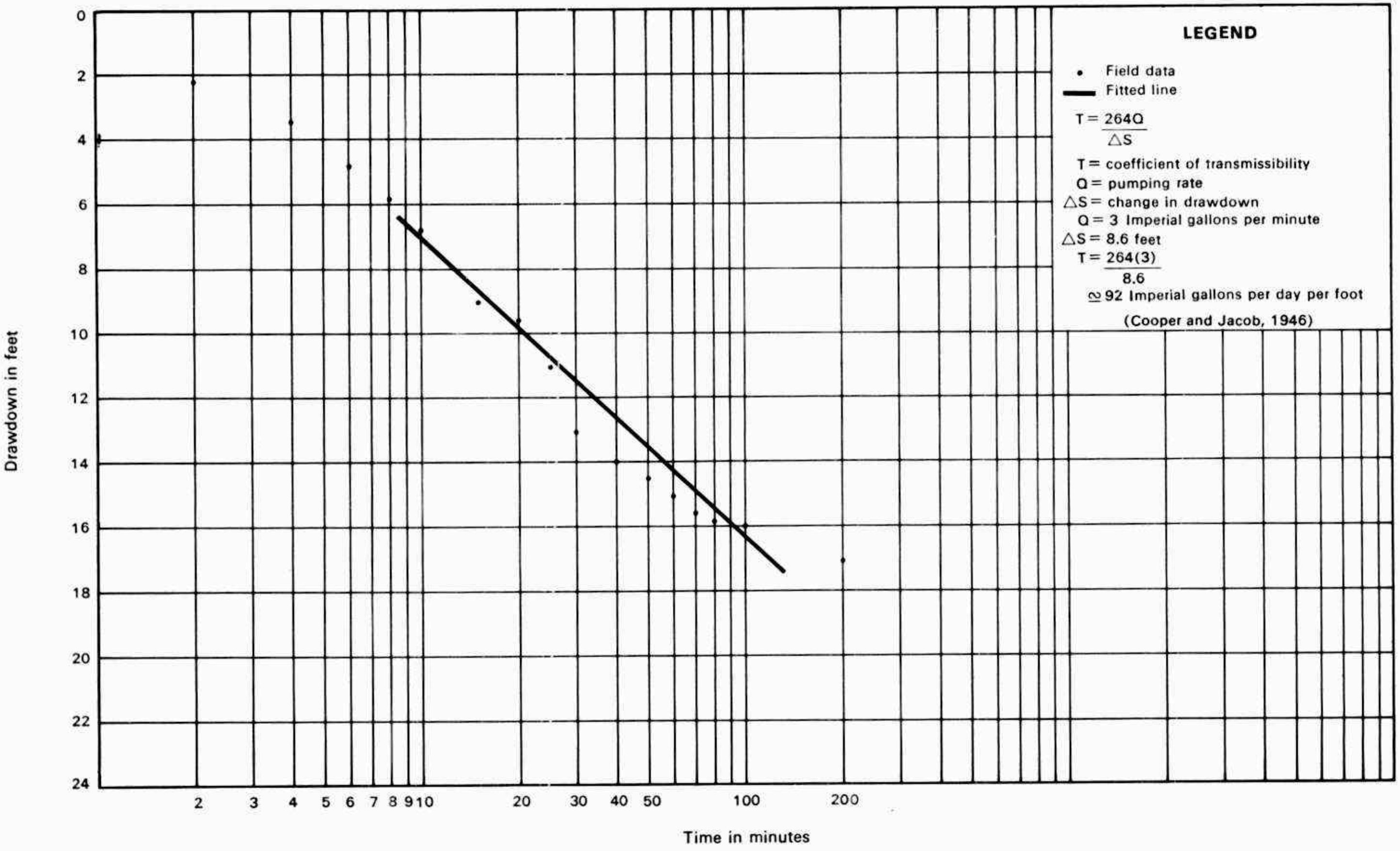


Figure 19. Time-drawdown data for pumped well WC-7.

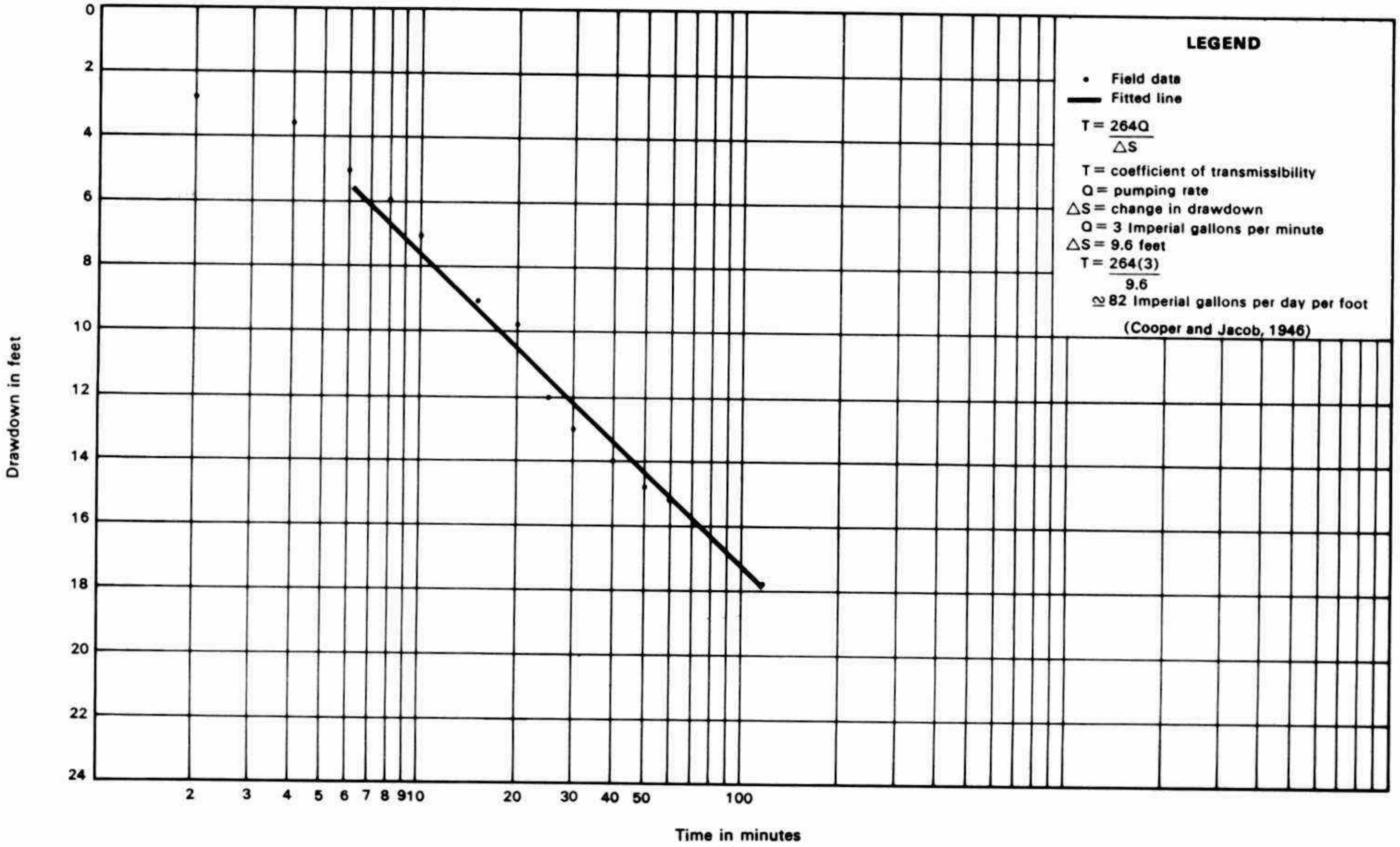


Figure 20. Time-drawdown data for pumped well WC-4.

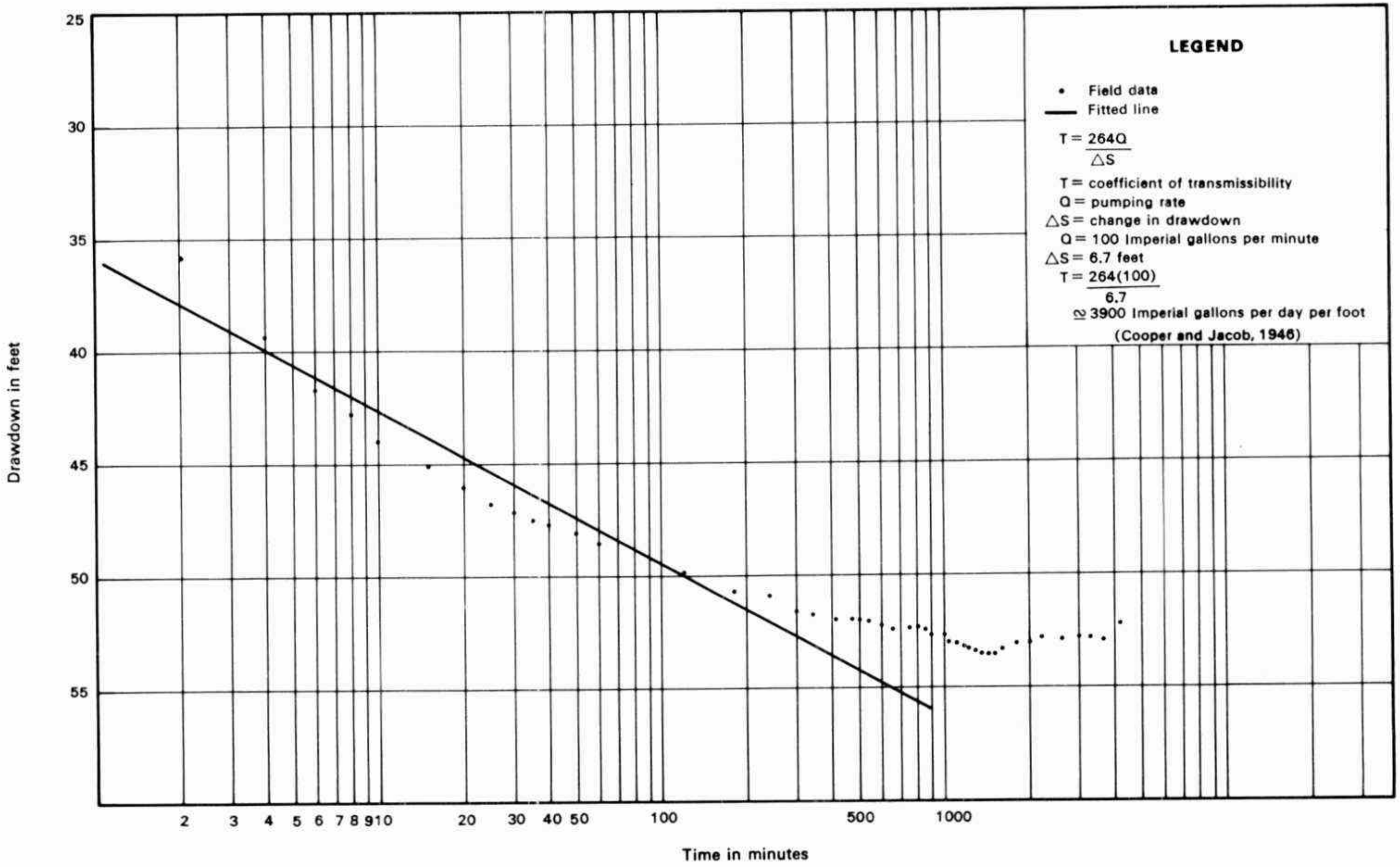


Figure 21. Time-drawdown data for pumped well at service centre E-5.

APPENDIX C

WATER QUALITY ANALYSES

Table 13. Results of chemical analyses of water samples.

Table 15. Grouping of water analyses by their areal distribution in the basin.

SAMPLE NO.	OWNER OR LOCATION (where applicable)	WELL DEPTH (FT)	DATE SAMPLED	pH		ALKALINITY as $CaCO_3$		Constituents in Milligrams/litre (mg/1)										TOTAL DISSOLVED SOLIDS mg/1	CONDUCTIVITY micromohs/cm		HARDNESS $CaCO_3$	TEMPERATURE °F FIELD
				FIELD	LAB	FIELD	LAB	CALCIUM Ca	MAGNESIUM Mg	SODIUM Na	POTASSIUM K	TOTAL IRON Fe	BICARBONATE ALK. HCO_3	CHLORIDE Cl	SULPHATE SO_4	TOTAL NITRATE N	TOTAL PHOSPHORUS P		FIELD	LAB		
WC-2	MOE	78	Oct. 17/73	7.6	7.7	220	227	85	17	17	2.3	1.8	277	37	51	0.1	0.02	400	440	600	282	47
WC-3	MOE	180																				
Piez.A		178	Oct. 16/73	8.3	6.9	30	6	520	132	768	15	*	7	2600	35	0.1	0.12	3200	5100	7400	1850	47
B		118	Oct. 16/73	9.9	9.0	25	32	15	8	99	3.3	*	24	119	110	0.1	0.05	750	510	680	70	47
C		46	Oct. 16/73	8.7	7.8	280	206	94	11	28	1.9	*	251	61	49	1.6	0.08	460	570	680	278	47
D		29	Oct. 16/73	8.7	7.8	340	217	72	26	14	3.9	8.3	265	35	51	0.1	0.23	470	400	600	288	48
WC-4	MOE	44	Oct. 17/73	8.5	7.5	260	268	200	24	58	4.8	4.5	327	255	98	0.1	0.08	840	720	1420	600	48
WC-5	MOE	103	Oct. 17/73	7.6	7.5	290	290	144	22	71	6.5	1.8	354	133	53	0.2	0.02	650	600	1020	376	47
WC-6	MOE	113																				
Piez.A		13	Oct. 17/73	8.9	8.5	205	190	23	15	93	7.6	0.4	212	71	46	0.1	0.05	420	500	680	120	47
B		45	Oct. 17/73	9.8	9.2	185	195	15	7	131	9.8	6.6	204	85	46	0.1	0.14	470	450	720	66	47
C		85	Oct. 17/73	8.9	8.9	245	31	80	4	120	13	48	37	134	300	0.1	0.82	720	680	1040	218	50
WC-7	MOE	23	Oct. 17/73	7.5	7.6	-	247	114	21	35	3.8	8.6	301	126	40	0.1	1.2	650	700	890	372	50
WC-1	MOE	81																				
Piez.A		25	Oct. 18/73	10.0	10.4	80	251	77	2	12	6.5	*	306	18	25	0.14	0.16	370	785	225	200	48
B		63	Oct. 18/73	10.0	9.9	35	39	17	<1	5	2.2	*	48	5	35	0.1	0.85	110	136	90	42	46
WC-8	MOE	189																				
Piez.R		29	Oct. 19/76	9.9	12.1	>500	1040	320	59	63	6.7	11	0	132	22	0.1	0.28	1250	5100	3100	1040	51
F		176	Oct. 19/76	9.8	10.6	20	121	330	75	305	38	*	111	1160	88	0.1	0.08	3070	3850	4000	1060	52

* Sample exhausted

TABLE 13

SAMPLE NO.	OWNER OR LOCATION (where applicable)	WELL DEPTH (FT)	DATE SAMPLED	pH		ALAKALINITY as $CaCO_3$		Constituents in Milligrams/litre (mg/l)										TOTAL DISSOLVED SOLIDS mg/l	CONDUCTIVITY micromohs/cm		HARDNESS $CaCO_3$	TEMPERATURE °F FIELD
				FIELD	LAB	FIELD	LAB	CALCIUM Ca	MAGNESIUM Mg	SODIUM Na	POTASSIUM K	TOTAL IRON Fe	BICARBONATE ALK. HCO_3	CHLORIDE Cl	SULPHATE SO_4	TOTAL NITRATE N	TOTAL PHOSPHORUS P		FIELD	LAB		
1	Birdsell	107	Oct. 16,17, 18/73	8.5	8.7	250	246	9	2	282	3.2	<0.05	271	158	150	0.1	0.012	800	1100	1300	30*	51
2	Hartington P.S.	78		7.0	7.5	360	360	125	30	56	4.1	0.30	439	104	55	0.1	0.001	660	820	1050	436	51
3	Leonards Garage	120	"	7.0	7.2	490	453	155	35	84	2.8	14	555	175	21	0.08	0.010	830	1080	1370	532	51
4	Hartington Farm Supply	109	"	8.0	7.9	220	235	37	11	230	13	0.10	270	151	210	0.28	0.072	850	1000	1340	138	51
5	R. Goslin	49	"	7.6	7.8	250	255	66	20	69	4.5	0.25	311	57	57	0.1	0.002	460	600	750	246	51
6	Hanna	53	"	7.1	7.6	300	275	98	20	37	1.9	<0.05	321	70	29	1.5	0.001	470	640	780	328	51
7	Bennett	65	"	7.7	7.6	390	364	52	30	164	13	0.10	410	140	51	1.5	0.001	700	910	1180	252	51
8	Harrowsmith Restaurant	60	"	7.1	7.3	410	434	123	40	91	7.5	0.50	271	114	59	0.1	0.028	740	1020	1220	472	51
9	Harrowsmith Post Office	70	"	7.1	7.4	380	360	131	38	91	11	0.15	336	145	100	5.6	0.026	820	1100	1300	484	51
10	Robinson	50	"	7.0	7.2	446	448	131	41	64	8.0	0.20	226	80	60	1.7	0.050	680	950	1140	496	51
11	Simmon's (Lamberts' Gar.)	48	"	6.8	7.3	370	372	149	26	40	2.0	1.10	273	104	41	0.1	0.022	730	850	1040	480	51
12	C. Hanson	60	"	8.2	7.8	210	219	83	18	39	3.1	0.50	254	78	44	0.3	0.001	440	550	710	282	47
13	Wistard	55	"	7.4	7.7	250	271	86	35	78	1.0	0.45	306	58	170	0.4	0.001	650	780	980	360	49
14	D. Gowdy	45	"	7.4	7.5	290	289	88	28	32	4.2	0.05	312	47	50	0.5	0.001	460	620	780	336	54
15	F. Kent	75	"	7.4	7.5	260	273	117	20	39	5.5	0.05	333	73	110	2.1	0.001	550	720	910	376	52
16	Harden	35	"	7.0	7.5	250	255	106	16	8	1.7	0.45	311	30	38	3.6	0.004	400	520	640	328	50
17	Dartt	105	"	7.8	7.7	320	279	92	24	8	2.0	<0.05	340	20	39	1.1	0.001	390	540	630	328	51
18	Steele	120	"	7.8	7.8	390	385	27	8	276	5.2	0.10	470	191	58	0.1	0.008	800	890	1410	102	52
19	A. Alkenbrack	19	"	7.4	7.6	280	306	80	35	18	5.3	0.10	373	20	49	3.0	0.037	460	520	700	348	51
20	L. Wannamaker	55	"	7.8	7.6	220	239	65	25	14	1.9	0.90	292	7	50	0.1	0.022	340	490	550	266	49
21	J. Chambers	80	"	7.5	7.5	500+	1140	104	77	540	68	0.15	1391	463	60	9.5	0.066	2130	3000	3350	576	55
22	P. Wycott	33	"	7.6	7.7	210	222	72	16	15	2.9	1.00	271	19	38	0.02	0.002	340	550	530	246	58
23	L. Lasher	65	"	7.3	7.6	240	247	81	16	55	4.0	0.25	301	71	51	0.1	0.001	450	620	840	270	55
35	G. Lasher	60	Nov. 16/73					42	27	290	9.6	<0.05	327	356	74	0.01		960		1750		

* Water Softner

SAMPLE NO.	OWNER OR LOCATION (where applicable)	WELL DEPTH (FT)	DATE SAMPLED	pH		ALKALINITY as $CaCO_3$		Constituents in Milligrams/litre (mg/l)											CONDUCTIVITY micromohs/cm			
				FIELD	LAB	FIELD	LAB	CALCIUM Ca	MAGNESIUM Mg	SODIUM Na	POTASSIUM K	TOTAL IRON Fe	BICARBONATE ALK. HCO_3	CHLORIDE Cl	SULPHATE SO_4	TOTAL NITRATE N	TOTAL DISSOLVED SOLIDS mg/l	HARDNESS $CaCO_3$	LAB			
DW 24		14	July 10/69		8.0		326	166	46	28	4.2	0.15	398	53	exh.		exh.		exh.			
DW 25		15	"		8.6		225	80	14	13	2.0	0.35	274	25	13		330		515			
DW 26		18	"		7.8		269	109	16	17	1.7	0.10	328	30	45		460		700			
DW 27		50	"		7.4		385	142	10	37	5.2	3.50	470	63	28		570		896			
DW 28		60	"		7.4		386	143	10	43	5.4	3.25	471	63	30		580		922			
DW 29		90	"		7.6		513	162	45	452	8.6	0.25	626	636	118		1670		2990			
DW 30		60	"		7.8		273	90	32	37	4.0	6.00	333	64	46		550		747			
DW 31		70	"		8.5		224	80	13	11	1.9	0.20	273	23	13		330		495			
DW 32		75	"		7.9		213	77	24	7	3.4	0.10	260	32	46		400		555			
DW 33		70	"		7.8		281	90	27	5	2.4	0.05	343	14	33		415		606			
DW 34		?	"		7.7		459	150	25	53	30	1.25	560	79	54		730		1110			
	? Shallow																					

SAMPLE NO.	OWNER OR LOCATION (where applicable)		DATE SAMPLED	pH		ALKALINITY as $CaCO_3$		Constituents in Milligrams/litre (mg/l)										HARDNESS $CaCO_3$	CONDUCTIVITY micromohs/cm			
				FIELD	LAB	FIELD	LAB	CALCIUM Ca	MAGNESIUM Mg	SODIUM Na	POTASSIUM K	TOTAL IRON Fe	BICARBONATE ALK. HCO_3	CHLORIDE Cl	SULPHATE SO_4	TOTAL NITRATE N	TOTAL DISSOLVED SOLIDS mg/l		LAB			
St. 2	Harrowsmith		Nov. 29/73		8.1		183	65	13	3	2.1	0.39	223	8	17	0.6	245	216	384			
" 3	"		Dec. 11/68		8.0		282	96	20	7	2.1	0.10	344	13	24	1.5	385	322	597			
" 4	"		Apr. 28,29/69		8.2		226	76	15	5	1.7	0.15	276	10	20	1.6	265	249	453			
" 13	"		July 10/69		8.8		247	86	19	7	1.4	0.70	301	exh.	14		350		515			
" 5	Wilton		Nov. 29/69		8.1		154	62	5	2	2.0	0.59	188	3	14	0.35	208	176	324			
" 6	"		Dec. 11/68		8.0		242	80	17	6	1.8	0.30	295	8	20	0.78	310	272	525			
" 7	"		Apr. 28,29/68		8.3		210	74	10	4	1.7	0.20	256	8	17	0.04	235	226	433			
" 1	Violet		Oct. 17/73	8.3	8.5	240	210	88	16	20	4.6	0.30	293	52	41	0.1	300	284	480			
" 12	"		July 10/69		8.4		225	80	13	12	1.9	0.20	256	24	13		340		495			
" 8	Fredricksburgh		Nov. 29/68		8.1		120	52	5	6	3.1	1.57	274	13	21	0.82	234	150	309			
" 9	"		Dec. 11/68		8.2		256	94	14	9	2.3	0.35	146	16	25	0.72	345	292	582			
" 10	"		Apr. 28.29/69		8.8		216	76	12	10	1.9	0.25	263	15	20	0.02	245	239	453			
" 11	"		July 10/69		8.6		222	79	14	14	3.0	0.25	271	26	20		340		515			

TABLE 15

HARROWSMITH-HARTINGTON AREA

No.	Title	Ca	Mg	Na	K	CL	ALK	SO_4	NO_3	Ca/Mg	HCO_3/SO_4	HCO_3/CL	SO_4/CL	ERROR %	SATC	SATD	SATG	SATM
1	WC1A	77.0	2.0	12.0	6.5	18.0	251.0	25.0	0.1	23.35	9.64	9.88	1.03	-12.62	2.218	2.900	-2.293	0.204
2	WC1B	17.0	1.0	5.0	2.2	5.0	39.0	35.0	0.1	10.31	1.07	5.53	5.17	-15.80	0.964	0.859	-2.481	-0.584
3	DW01	9.0	2.0	282.0	3.2	158.0	246.0	150.0	0.1	2.73	1.57	1.10	0.70	1.80	0.426	0.397	-2.378	-0.508
4	DW02	125.0	30.0	56.0	4.1	104.0	360.0	55.0	0.1	2.53	6.28	2.45	0.39	-0.15	0.592	0.800	-1.734	-0.271
5	DW03	155.0	35.0	84.0	2.8	175.0	455.0	21.0	0.1	2.69	20.79	1.84	0.09	-0.46	0.466	0.530	-2.109	-0.414
6	DW04	37.0	11.0	230.0	1.3	151.0	235.0	210.0	0.3	2.04	1.07	1.10	1.03	-2.14	0.247	0.184	-1.647	-0.541
7	DW05	66.0	20.0	69.0	4.5	57.0	255.0	57.0	0.1	2.00	4.29	3.17	0.74	0.99	0.507	0.721	-1.896	-0.264
8	DW06	98.0	20.0	37.0	1.9	70.0	275.0	29.0	1.5	2.97	9.10	2.78	0.31	0.08	0.513	0.566	-2.040	-0.425
9	DW07	52.0	30.0	164.0	13.0	140.0	364.0	51.0	1.5	1.05	6.85	1.84	0.27	0.55	0.323	0.641	-2.109	-0.160
10	DW08	123.0	40.0	91.0	7.5	114.0	434.0	59.0	0.1	1.87	7.06	2.70	0.38	1.70	0.448	0.649	-1.745	-0.278
11	DW09	131.0	38.0	91.0	11.0	145.0	360.0	100.0	5.6	2.09	3.46	1.76	0.51	0.50	0.486	0.670	-1.497	-0.295
12	DW10	131.0	41.0	64.0	8.0	80.0	448.0	60.0	1.7	1.94	7.17	3.97	0.55	1.25	0.391	0.518	-1.712	-0.351
13	DW11	149.0	26.0	40.0	2.0	104.0	372.0	41.0	0.1	3.48	8.71	2.53	0.29	0.61	0.484	0.448	-1.794	-0.515
14	DW12	83.0	18.0	39.0	3.1	78.0	219.0	44.0	0.3	2.80	4.78	1.99	0.42	-0.77	0.548	0.659	-1.907	-0.368
15	DW13	86.0	35.0	78.0	10.0	58.0	271.0	170.0	0.4	1.49	1.53	3.31	2.16	0.93	0.491	0.814	-1.400	-0.155
16	DW14	88.0	28.0	32.0	4.2	47.0	289.0	50.0	0.5	1.91	5.55	4.36	0.79	0.10	0.382	0.497	-1.861	-0.363
17	DW15	117.0	20.0	39.0	5.5	73.0	273.0	110.0	2.1	3.55	2.38	2.65	1.11	-3.29	0.452	0.363	-1.432	-0.567
18	DW16	106.0	16.0	8.0	1.7	30.0	255.0	38.0	3.6	4.02	6.44	6.02	0.93	0.05	0.424	0.256	-1.875	-0.646
19	DW17	92.0	24.0	8.0	2.0	20.0	279.0	39.0	1.1	2.33	6.87	9.88	1.44	-0.47	0.595	0.837	-1.930	-0.237
20	DW18	27.0	8.0	276.0	5.2	191.0	385.0	58.0	0.1	2.05	6.37	1.43	0.22	-0.53	0.255	0.214	-2.310	-0.519
21	DW33	90.0	27.0	5.0	2.4	14.0	281.0	33.0	0.0	2.02	8.17	14.22	1.74	2.15	0.688	1.082	-2.012	-0.084
22	DW34	150.0	25.0	53.0	30.0	79.0	459.0	54.0	0.0	3.64	8.16	4.12	0.50	0.36	0.953	1.366	-1.690	-0.066
Mean		91.3	22.5	80.1	6.0	86.6	309.3	67.6	0.9	3.77	6.24	4.03	0.94		0.584	0.726	-1.902	-0.337

VIOLET AREA GROUP B SAMPLES

No.	Title	Ca	Mg	Na	K	CL	ALK	SO_4	Ca/Mg	HCO_3/SO_4	HCO_3/CL	SO_4/CL	ERROR %	SATC	SATD	SATG	SATM
1	DW29	162.0	45.0	452.0	8.6	636.0	513.0	118.0	2.18	4.17	0.57	0.14	1.64	0.838	1.364	-1.477	-0.048
2	WC3A	520.0	132.0	768.0	15.0	2600.0	6.0	35.0	2.39	0.16	0.00	0.01	-2.48	-1.391	-3.121	-1.768	-2.209
3	WC3B	15.0	8.0	99.0	3.3	119.0	32.0	110.0	1.14	0.28	0.19	0.68	-4.10	0.120	0.171	-2.162	-0.427
4	WC6C	80.0	4.0	120.0	13.0	134.0	31.0	300.0	12.13	0.10	0.16	1.65	-3.80	0.630	0.161	-1.159	-0.948
Mean		194.3	47.3	359.8	10.0	872.3	145.5	140.7	4.4	1.20	0.25	0.64		0.052	-0.362	-1.609	-0.899

VIOLET AREA GROUP A SAMPLES

No.	Title	Ca	Mg	Na	K	CL	ALK	SO_4	Ca/ Mg	HCO_3/ SO_4	HCO_3/ CL	SO_4/ CL	ERROR %	SATC	SATD	SATG	SATM
1	WC2	85.0	17.0	17.0	2.3	37.0	227.0	51.0	3.03	4.27	4.35	1.02	-1.61	0.481	0.490	-1.823	-0.470
2	WC3C	94.0	11.0	28.0	1.9	61.0	206.0	49.0	5.18	4.03	2.39	0.59	-0.79	0.580	0.453	-1.797	-0.605
3	WC3D	72.0	26.0	14.0	3.9	35.0	217.0	51.0	1.68	4.08	4.39	1.08	0.37	0.489	0.761	-1.897	-0.207
4	WC4	200.0	24.0	58.0	4.8	255.0	268.0	98.0	5.05	2.62	0.74	0.28	0.02	0.635	0.581	-1.345	-0.532
5	WC5	114.0	22.0	71.0	6.5	133.0	290.0	53.0	3.14	5.25	1.54	0.29	0.42	0.473	0.464	-1.761	-0.488
6	WC6A	23.0	15.0	93.0	7.6	71.0	190.0	46.0	0.93	3.96	1.90	0.48	-1.07	0.621	1.265	-2.379	0.166
7	WC6B	15.0	7.0	131.0	9.8	85.0	195.0	46.0	1.30	4.07	1.63	0.40	0.10	1.019	1.873	-2.594	0.375
8	WC7	114.0	21.0	35.0	3.8	126.0	247.0	40.0	3.29	5.93	1.39	0.23	-1.60	0.519	0.534	-1.861	-0.463
9	DW22	72.0	16.0	15.0	2.9	19.0	222.0	38.0	2.73	5.61	8.28	1.48	-1.12	0.416	0.406	-1.993	-0.489
10	DW23	81.0	16.0	55.0	4.0	71.0	247.0	51.0	3.07	4.65	2.46	0.53	-0.97	0.387	0.298	-1.857	-0.567
11	DW30	90.0	32.0	37.0	4.0	64.0	273.0	46.0	1.71	5.70	3.02	0.53	3.62	0.657	1.095	-1.898	-0.041
12	DW31	80.0	13.0	11.0	1.9	23.0	224.0	13.0	3.73	16.54	6.90	0.42	1.76	1.229	1.880	-2.412	0.173
13	DW32	77.0	24.0	7.0	3.4	32.0	213.0	46.0	1.95	4.44	4.72	1.06	0.74	0.611	0.939	-1.909	-0.150
Mean		85.9	18.7	44.0	4.3	77.8	232.2	48.3	2.83	5.47	3.36	0.65		0.624	0.849	-1.964	-0.254

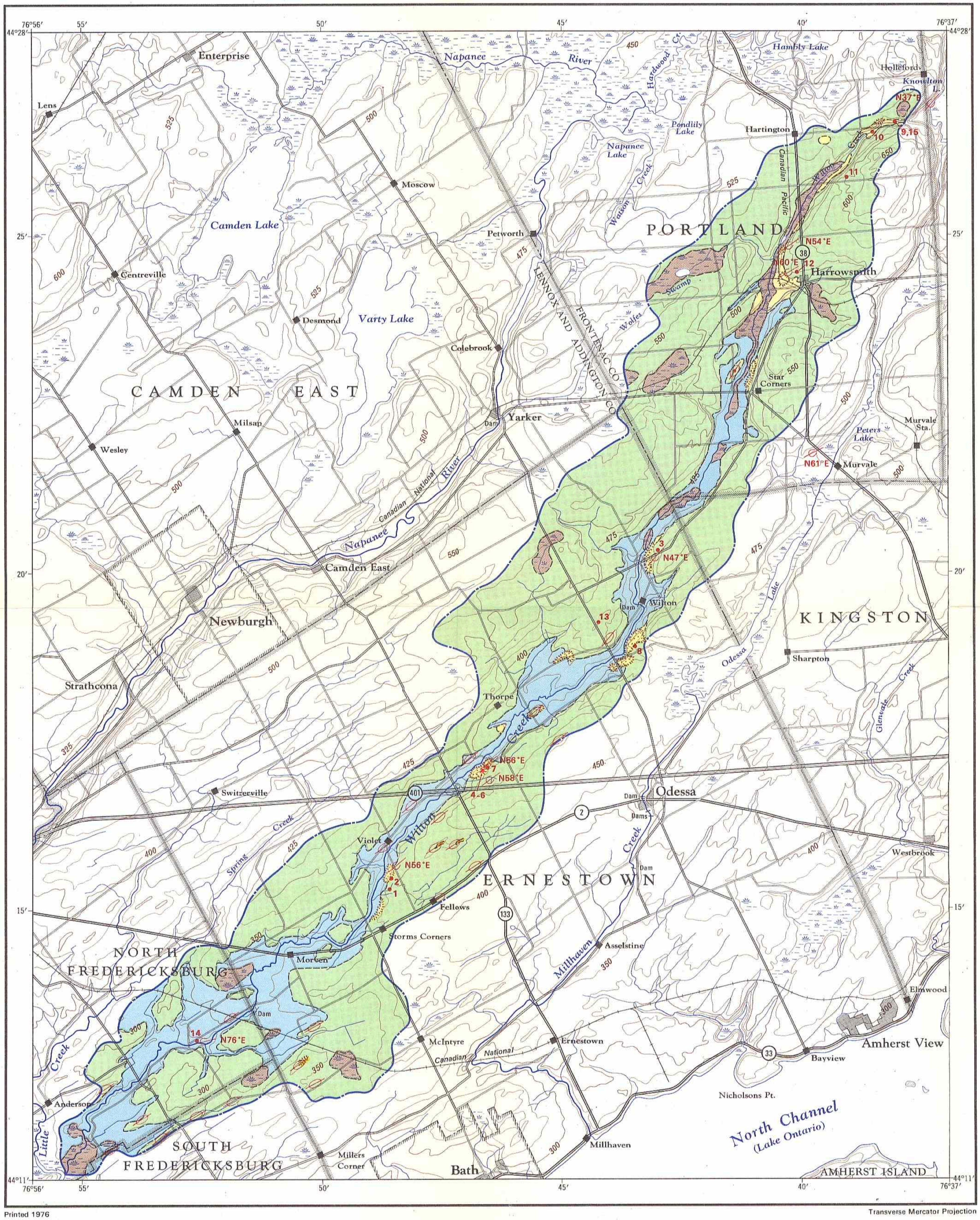
CHAMBERS AREA GROUP D SAMPLES

No.	Title	Ca	Mg	Na	K	CL	ALK	SO_4	Ca/ Mg	HCO_3/ SO_4	HCO_3/ CL	SO_4/ CL	ERROR %	SATC	SATD	SATG	SATM
1	WC8F	300.0	75.0	305.0	38.0	1160.0	121.0	88.0	2.43	1.32	0.07	0.06	-2.21	1.997	3.567	-1.414	1.091
2	DW21	104.0	77.0	540.0	68.0	463.0	1140.0	60.0	0.82	18.24	1.74	0.10	-1.36	0.847	1.828	-2.023	0.503
Mean		202.0	76.0	422.5	53.0	811.5	630.5	74.0	1.62	9.78	0.91	0.08		1.422	2.698	-1.718	0.797

CHAMBERS AREA GROUP C SAMPLES

No.	Title	Ca	Mg	Na	K	CL	ALK	SO_4	CA/ Mg	HCO_3/ SO_4	HCO_3/ CL	SO_4/ CL	ERROR %	SATC	SATD	SATG	SATM
1	WC8R	320.0	59.0	63.0	6.7	132.0	1040.0	22.0	3.29	45.37	5.58	0.12	-2.54	2.967	5.002	-2.202	1.557
2	DW19	80.0	35.0	18.0	5.3	20.0	306.0	49.0	1.39	5.99	10.84	1.81	-0.79	0.464	0.800	-1.913	-0.142
3	DW20	65.0	25.0	14.0	1.9	7.0	239.0	50.0	1.58	4.59	24.19	5.27	-0.53	0.296	0.403	-1.937	-0.371
4	DW24	166.0	46.0	28.0	4.2	53.0	326.0	*	2.19	*	4.36	*	25.16	1.156	1.987	*	0.352
5	DW25	80.0	14.0	13.0	2.0	25.0	225.0	13.0	3.47	5.74	6.35	1.11	2.57	1.315	2.081	-2.418	0.287
6	DW26	109.0	16.0	17.0	1.7	30.0	269.0	45.0	4.13	5.74	6.35	1.11	2.59	0.745	0.885	-1.800	-0.339
7	DW27	142.0	10.0	37.0	5.2	63.0	385.0	28.0	8.61	13.20	4.33	0.33	-2.04	0.595	0.275	-1.937	-0.798
8	DW28	143.0	10.0	43.0	5.4	63.0	386.0	30.0	8.67	12.35	4.34	0.35	-0.74	0.597	0.276	-1.907	-0.799
Mean		138.1	26.8	29.1	4.0	49.1	397.0	33.8	4.17	14.84	8.30	1.34		1.017	1.464	-2.016	-0.032

* Sample depleted - analyses not run



Printed 1976

Transverse Mercator Projection

LEGEND

CENOZOIC

PLEISTOCENE

RECENT

🟫	**Swamp and alluvial deposits:** the alluvial deposits are limited in areal extent, being confined to the vicinity of Wilton Creek. Mainly clay, silt and fine sand. The swamp deposits, comprised of peat, muck, silt and fine sand, are more extensive.

WISCONSINAN

🟦	**Fine-grained glaciolacustrine deposits:** mainly clay and silt. These deposits are of limited thickness and discontinuous in areal extent.
🟨	**Coarse-grained glaciolacustrine deposits:** well-stratified gravel and sand beach and bar deposits, representing a brief water stand.
🟩	**Glacial deposits:** primarily sandy-silty till in ground moraine and drumlin deposits.
🟨	**Glaciofluvial deposits:** stratified sand, silt and gravel with extreme range in grain size, sorting and structure.

SYMBOLS

	Geological boundary, approximate
300	Topographic contour
	Sand and gravel pit
N76°E	Glacial striae
	Drumlins
	Drumlinoids
● 8	Overburden sample locations

SOURCES OF INFORMATION

Surficial geology compiled by G. Funk, 1973.
Information supplemented with data from:
Mirynech, E., 1967-68, Unpublished field notes for Bath-Sydenham map area.

To accompany Water Resources Report 7

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

WILTON CREEK DRAINAGE BASIN

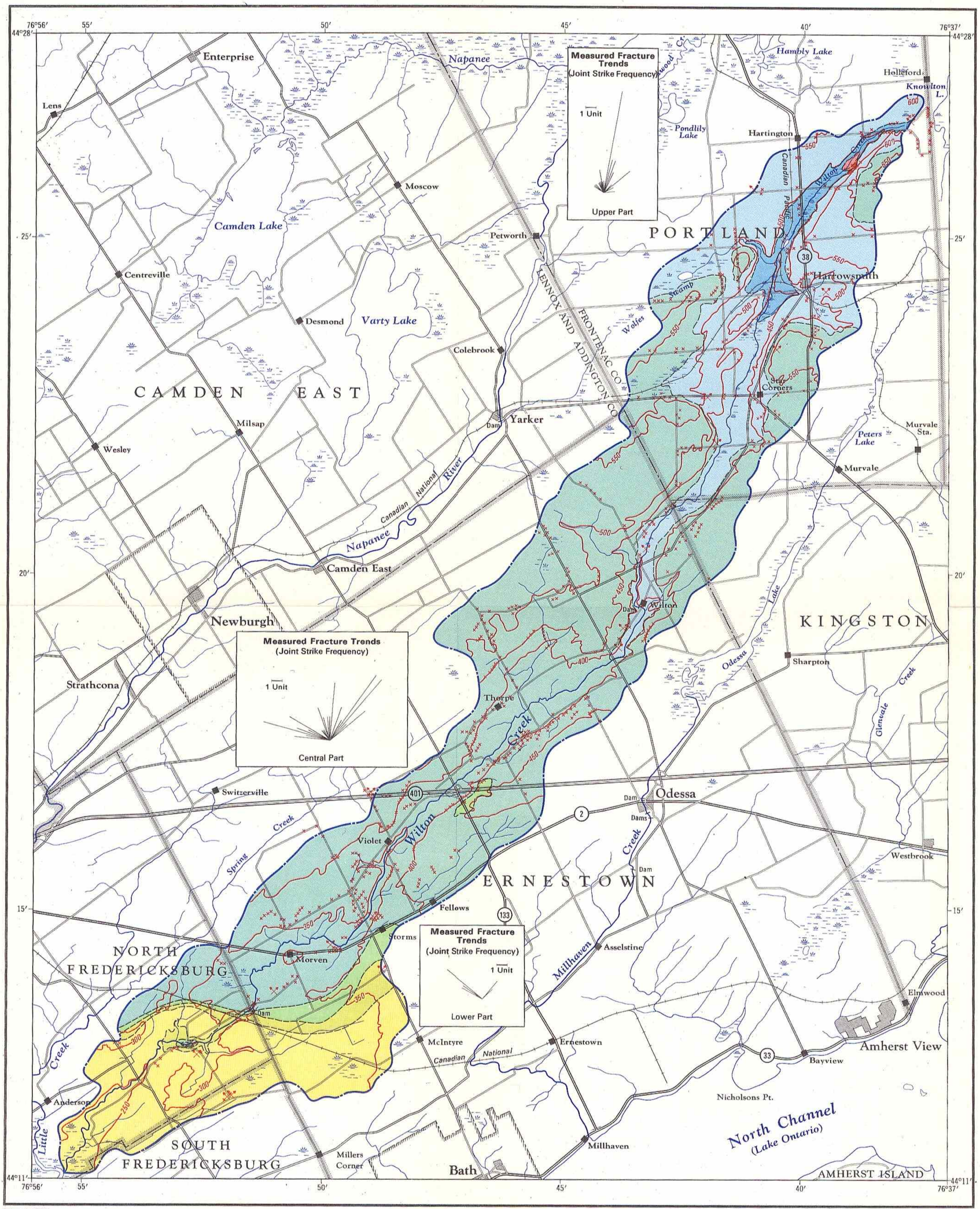
MAP 2

SURFICIAL GEOLOGY

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres



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Transverse Mercator Projection

LEGEND

PALEOZOIC

ORDOVICIAN

🟨	**Verulam Formation**
🟨	**Bobcaygeon Formation:** Upper Member
🟩	**Bobcaygeon Formation:** Lower Member
🟩	**Gull River Formation:** Members B,C,D
🟦	**Gull River Formation:** Member A, upper submember
🟦	**Gull River Formation:** Member A, lower and middle submembers
🟧	**Shadow Lake Formation**

PRECAMBRIAN

🟥	Precambrian rocks, undifferentiated

SYMBOLS

- - -	Geological boundary, approximate
—650—	Bedrock surface contour, interval 50 feet
×××××	Outcrop exposure
⚒	Quarry

SOURCES OF INFORMATION

Bedrock geology and topography as modified from Liberty, 1971, by G. Funk, 1973, from cited reference, water-well records assembled by the Ministry of the Environment, field surveys and personal communication with B.A. Liberty.

Liberty, B.A., 1971, Paleozoic geology of Wolfe Island, Bath, Sydenham and Gananoque map-areas, Ontario; Geol. Surv. Can., Paper 70-35.

To accompany Water Resources Report 7

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

WILTON CREEK DRAINAGE BASIN

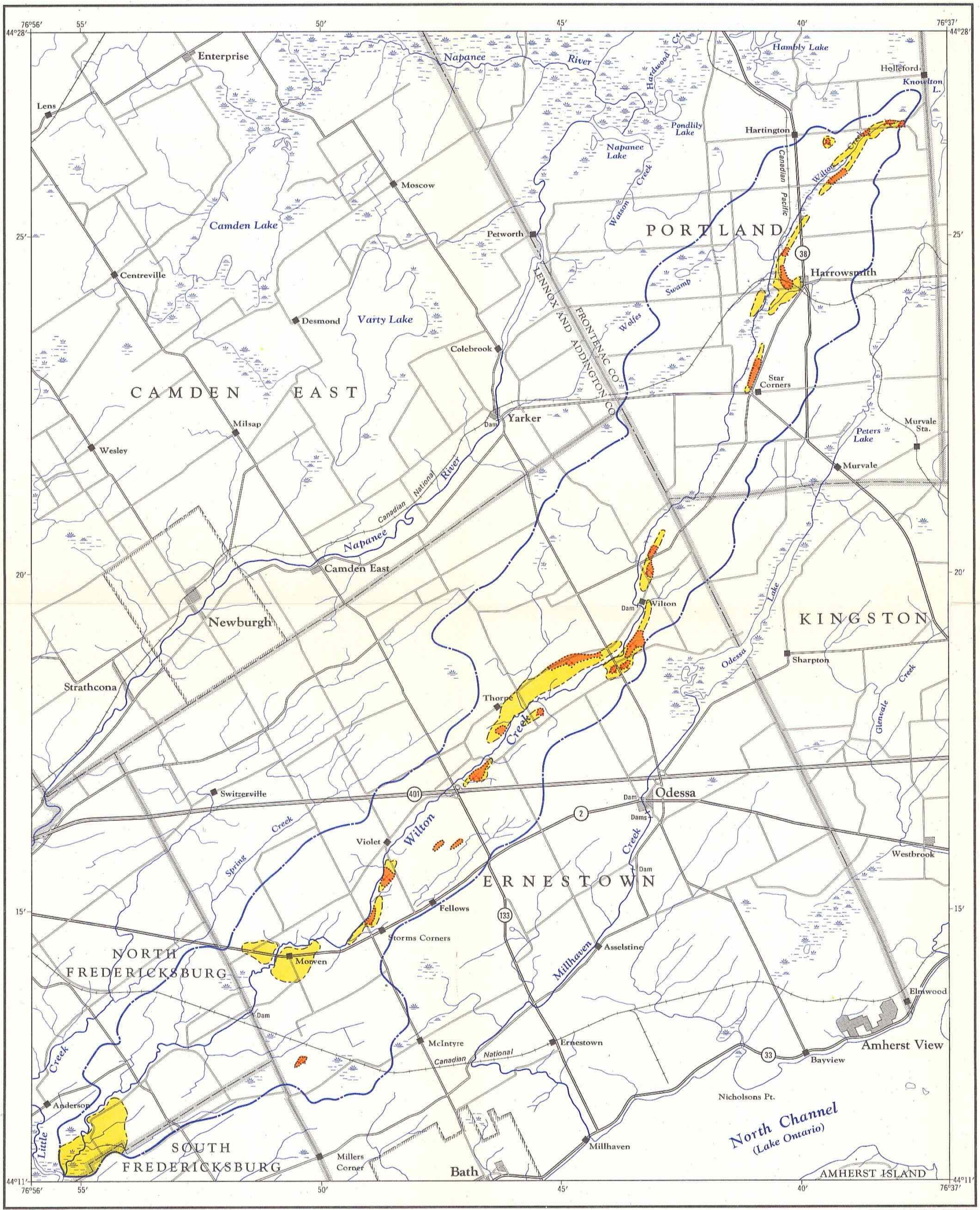
MAP 1

BEDROCK GEOLOGY AND TOPOGRAPHY

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres



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Transverse Mercator Projection

LEGEND

🟧 Exposed deposits

🟨 Buried deposits

SYMBOLS

┈ Geological boundary, approximate

╌ Geological boundary, assumed

✕ Sand and gravel pit

SOURCES OF INFORMATION

Sand and gravel deposits and their areal extent, as delineated by G. Funk, 1973, from water-well records assembled by the Ministry of the Environment and from field surveys.

To accompany Water Resources Report 7

Ontario

MINISTRY OF THE ENVIRONMENT
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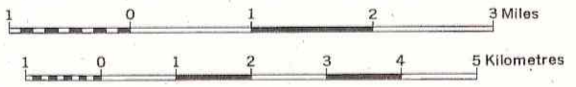
INTERNATIONAL HYDROLOGICAL DECADE

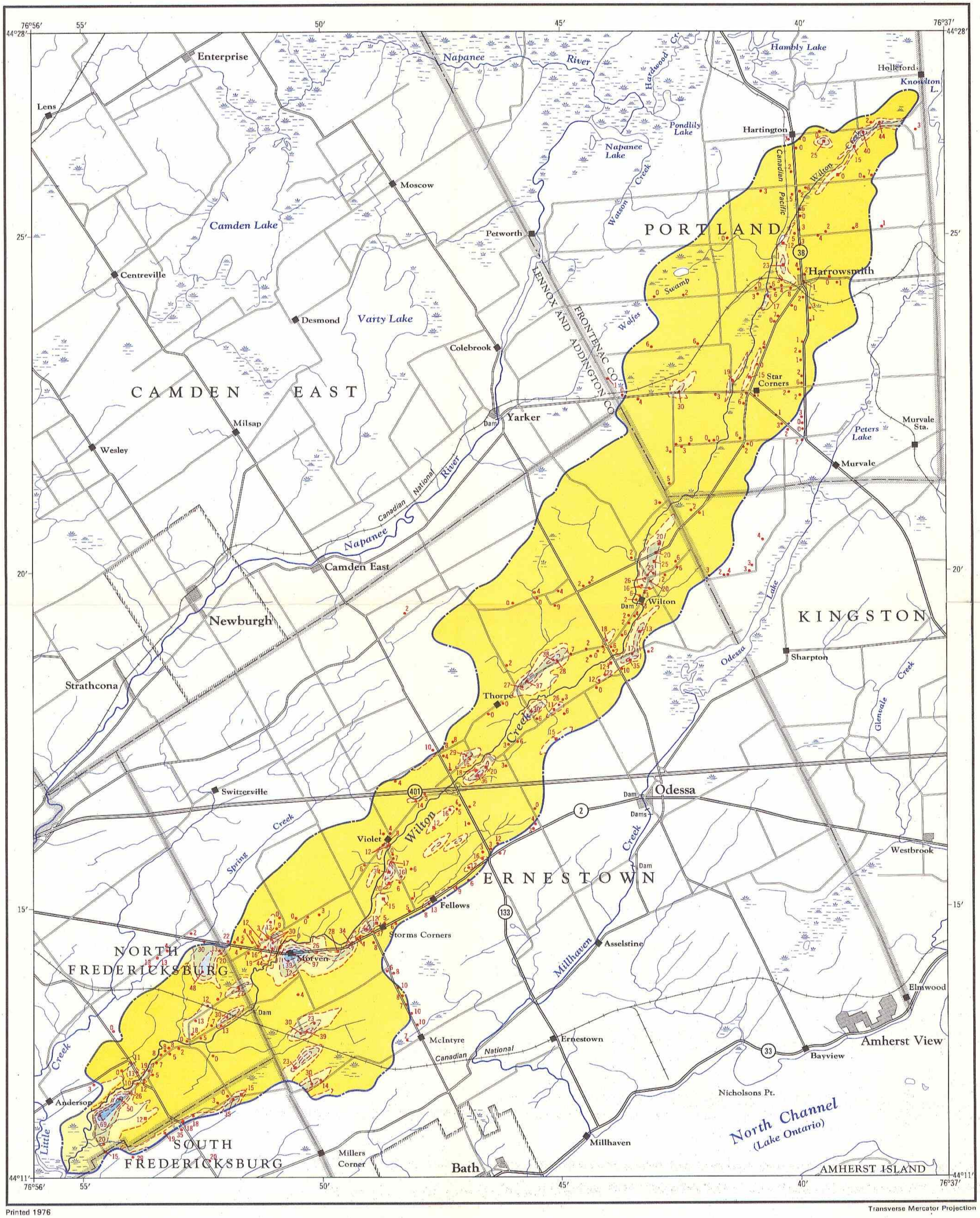
WILTON CREEK DRAINAGE BASIN

MAP 4

SAND AND GRAVEL DEPOSITS

Scale 1:100,000
1 inch equals 1.58 miles





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Transverse Mercator Projection

LEGEND

Thickness of Overburden

🟨	0-10 feet
🟨	10-20 feet
🟩	20-30 feet
🟦	30-40 feet
🟦	More than 40 feet

SYMBOLS

- - -	Line of equal overburden thickness (isopach), interval 10 feet
• 12	Observed overburden thickness
• 25	Overburden thickness from water-well records, in feet

SOURCES OF INFORMATION

Overburden thickness compiled by G. Funk, 1973, from field surveys and water-well records on file with the Ministry of the Environment.

To accompany Water Resources Report 7

Ontario

MINISTRY OF THE ENVIRONMENT

Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

WILTON CREEK DRAINAGE BASIN

MAP 3

OVERBURDEN THICKNESS

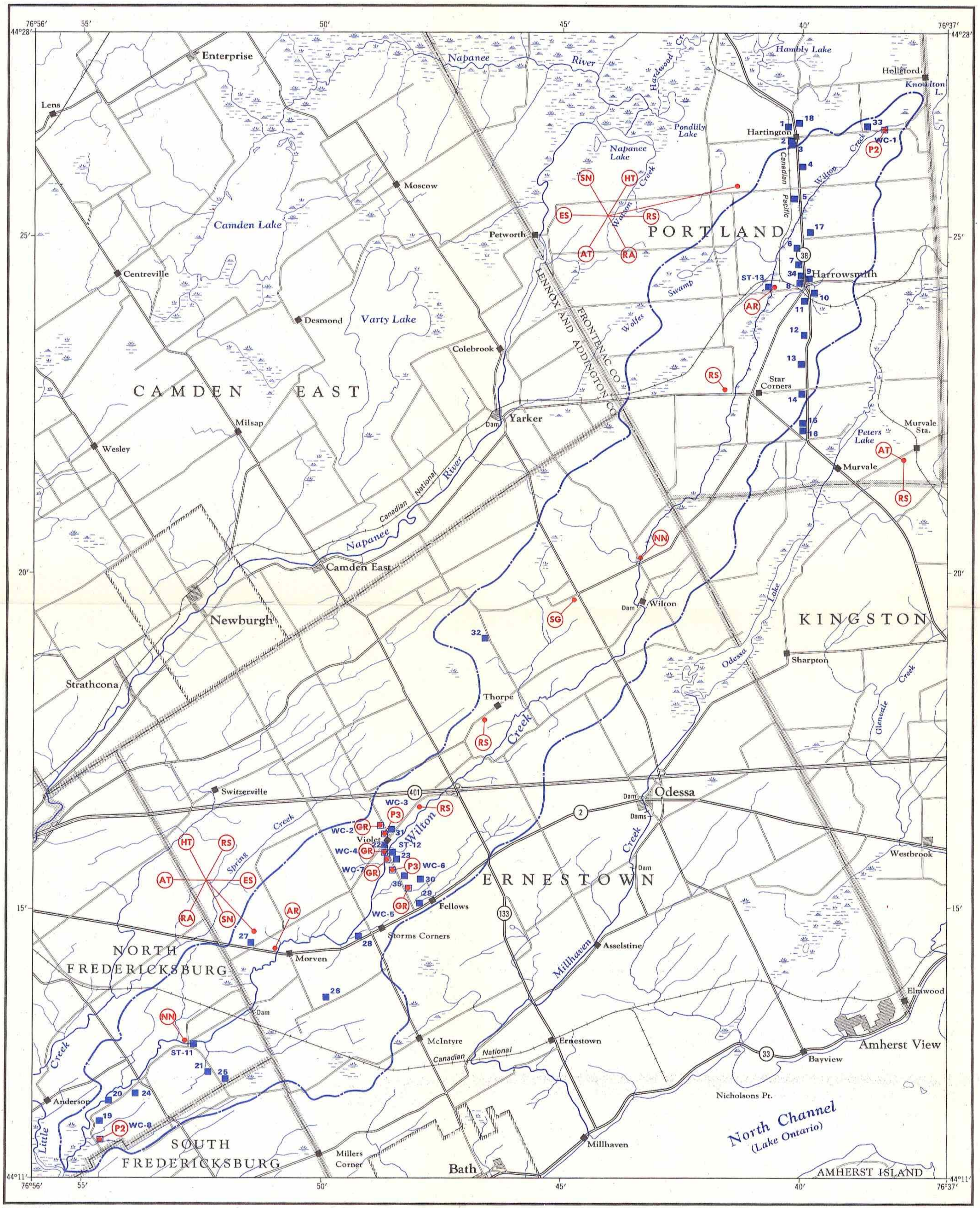
Scale 1:100,000

1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres

MAP 4756-10



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Transverse Mercator Projection

LEGEND

NN	Hydrometric station, natural control, non-recording
AR	Hydrometric station, artificial control, recording
GR	Ground-water well, recording
P*	Piezometer (asterisk replaced by number of piezometers in nest)
SG	Snow gauge
RA	Rain gauge, recording
RS	Rain gauge, standard
HT	Hygrothermograph
SN	Radiometer
ES	Evaporation station
AT	Air temperature

SYMBOLS

☐ WC-3	Water sample collected from MOE observation well
■ 19	Water sample collected from domestic well
■ ST-12	Water sample collected from stream

SOURCES OF INFORMATION

Water samples collected on field surveys in 1969 and 1973.

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MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

WILTON CREEK DRAINAGE BASIN

MAP 6

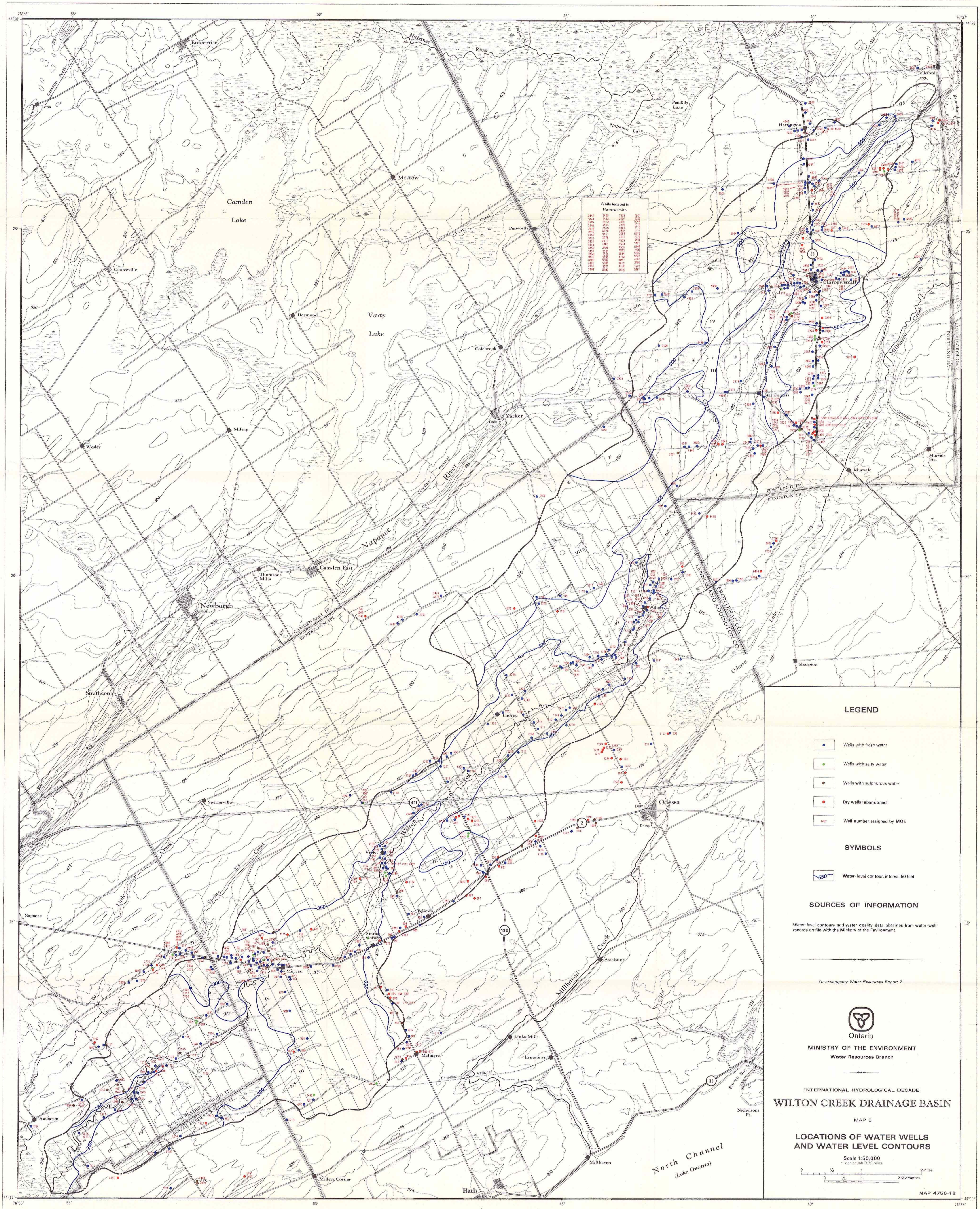
INSTRUMENTATION AND WATER SAMPLE COLLECTION SITES

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres

MAP 4756-13



LEGEND

●	Wells with fresh water
●	Wells with salty water
●	Wells with sulphurous water
●	Dry wells (abandoned)
1457	Well number assigned by MOE

SYMBOLS

550	Water-level contour, interval 50 feet

SOURCES OF INFORMATION

Water-level contours and water quality data obtained from water-well records on file with the Ministry of the Environment.

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MINISTRY OF THE ENVIRONMENT

Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

WILTON CREEK DRAINAGE BASIN

MAP 5

LOCATIONS OF WATER WELLS AND WATER LEVEL CONTOURS

Scale 1:50,000
1 inch equals 0.79 miles

0 ½ 1 2 Miles
0 ½ 1 2 Kilometres

MAP 4756-12

Printed 1976

Transverse Mercator Projection

Figure 3. Gamma logs for Ministry of the Environment observation wells on a cross-section near Violet.